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MPRE FUEL ELEMENTS: MANUFACTURE,
INSPECTION, DRAWINGS, AND SPECIFICATIONS

(Title Unclassified)

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MPRE FUEL ELEMENTS: MANUFACTURE, INSPECTION,
DRAWINGS, AND SPECIFICATIONS

G. M. Tolson

ABSTRACT

The Medium Power Reactor Experiment (MPRE) is a prototype of a boiling-potassium reactor in a single-loop nuclear power plant suitable for a variety of space missions. The fuel elements consist of highly enriched UO_2 pellets in type 316H stainless steel tubular cladding. Beryllium oxide pellets above the UO_2 serve as a reflector and in conjunction with a gadolinium aluminate pellet provide a thermal-neutron shield to suppress activation of the upper regions of the reactor. The report describes the specifications, methods of manufacture and inspection of the components, and assembly and inspection of the finished fuel element. Appendices contain as-built drawings and specifications as well as vendor manufacturing and inspection procedures.

INTRODUCTION

The Medium Power Reactor Experiment (MPRE) is a prototype of a boiling-potassium reactor in a single-loop nuclear power plant suitable for a variety of space, lunar, and terrestrial applications in which high output, low specific weight, and high reliability are essential. The system is designed so that the potassium serves as the coolant for the reactor, the working fluid for the thermodynamic cycle, the lubricant for the bearings in the turbine-generator, and the coolant for the generator. A vertical section through the MPRE is shown in Fig. 1. Liquid potassium at $1540^\circ F$ and 29 psi enters the core at the bottom, rises between the cluster of 241 0.5-in.-diam fuel elements, emerges from the core at a vapor quality of about 20%, and enters the vapor separator, where the liquid is discharged to the expansion tank directly beneath the vapor separator. The vapor passes radially outward at the bottom of the vapor separator, then goes upward around the perimeter, and leaves through the exit pipe at the top. The liquid potassium from the boiler feed pump enters a set of four jet pumps operating in parallel

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Fig. 1. Vertical Section Through the MPRE.

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at the bottom of the expansion tank. These pumps draw liquid from the expansion tank and discharge it to the core inlet. The annular side reflector consists of BeO tiles 1 1/2 in. high and 3 in. in radial thickness.

A schematic of fuel elements for use in the MPRE hot critical experiment and possibly in the reactor is shown in Fig. 2. These fuel elements consist of 93%-enriched UO_2 pellets in stainless steel tubular cladding. An MgO spacer is provided at the bottom of each element to shield the end cap from the central temperature of the UO_2 . Beryllium oxide pellets placed above the UO_2 serve as a reflector and in conjunction with gadolinium aluminate pellets provide a thermal-neutron shield to suppress activation of the upper regions of the reactor. A TZM alloy spring in the space provided for fission product gas accumulation keeps the pellets in a compact column. A plunger is provided to limit the movement of the pellet stack if the spring does not function. The fuel element is free standing and is sealed with 0.5 atm helium so that the external and internal pressures will be about equal at operating conditions. Three sets of six spacers are brazed to the cladding with Microbraz-50 (Ni-13% Cr-10% P).

DEVELOPMENT OF SPECIFICATIONS AND FABRICATION METHODS

To save time and money, we decided to build the fuel elements for the hot critical test of the MPRE to reactor standards so that, if circumstances permit, they could also be used for fueling the reactor. The fabrication methods to be used were essentially those developed¹ on Core I of the EGCR. Fabrication techniques for the EGCR could not be used for the following items:

1. Making the fuel element closure weld at 0.5 atm.
2. Attaching spacers; they could not be brazed with copper, which has poor corrosion resistance in potassium.

¹G. M. Tolson and M. G. Arlotti, "The Manufacture of EGCR Core I Fuel Assemblies," Welding J. 43(4), 280-86 (April 1964).

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Fig. 2. Schematic Representation of MPRE Fuel Element.

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3. Specifying, designing, and manufacturing the TZM spring, $Gd_2O_3-Al_2O_3$ pellets, and BeO pellets.

The Welding and Brazing Group determined the feasibility of fuel-element closure welding at reduced pressure.² They established welding conditions and a joint design that would produce welds to meet the specified requirements. The internal pressure of the simulated capsules was verified to remain at 0.5 atm, and the internal atmosphere met the required purity of 95% He.

We sought to determine the best method of putting spacers on the fuel elements. The methods considered were brazing, electron beam welding, use of finned tubing, and cold forming. Brazing was selected for the following reasons:

1. In the other methods, the fuel elements tube could be damaged in a manner that was not detectable by nondestructive methods.
2. There would be a considerable saving in cost.
3. In the areas where other methods were superior (e.g., corrosion, strength, and grain growth), brazing appeared adequate. Nicrobraz 50 was chosen tentatively as the brazing material because of its adequate corrosion resistance, lower brazing temperature with minimized grain growth, and absence of boron, which would form helium under irradiation.

The spring material, TZM, was selected by the Mechanical Properties Group because of its high-temperature strength. The springs that were made for the fuel element did not have satisfactory room temperature properties, however, and relaxed very easily. They were used in these elements since gravity would keep the pellets in place in both the hot critical test and the MPRE. Because conventional spring materials do not perform well at 1600°F, additional development will be required on a spring capable of performing satisfactorily at reactor conditions.³

For $Gd_2O_3-Al_2O_3$, we selected fabrication techniques and specifications that had been developed for use in the control element for the

²C. W. Fox, Development of Procedure for Welding Fuel Element End-Closures at Reduced Pressure, ORNL-TM-1130 (June 1965), (classified).

³W. J. Besemer and V. A. Stanton, "Springs for Use at High Temperature," Metal Progr. 87(4), 84-86 (April 1965).

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Molten-Salt Reactor Experiment.^{4,5} The specification for beryllium oxide was prepared from criteria furnished by the Ceramics Group.

Based on the above criteria and liaison work with various manufacturers, drawings and specifications were prepared. Appendices A and B contain specifications and drawings, respectively, describing the as-built components. The preliminary drawings were submitted for criticism to various fuel element manufacturers and to personnel at ORNL and Y-12 who were familiar with such work. Where possible, the comments were incorporated into the final drawings and specifications.

In addition to 296 fuel elements (including 55 spares) needed for the hot critical test, 4 prototype elements and 160 UO₂ pellets were required for in-reactor tests.⁶ These prototype elements and pellets were to be made by the same manufacturing methods used to make the MPRE elements. The UO₂ used in the prototype was enriched to 7% to permit testing in a thermal flux. A full-time burnup test (equivalent to 10,000 hr full-time operation) will be run on MPRE prototype elements before the startup of the reactor. The additional pellets were to be used in an in-reactor extensometer test to measure the variation in height of a stack of pellets with temperature.

The specifications and drawings were issued, and after competitive bidding the prime contract for the manufacture of the fuel elements was awarded to Westinghouse Electric Corporation, Atomic Power Division (APD), in September 1964.

COMPONENT MANUFACTURE

Most of the components were obtained from subvendors by Westinghouse-APD. These parts were inspected at the Westinghouse plant and witnessed by an ORNL inspector. Figures 3 and 4 show all of the

⁴"Manufacture of MSRE Control Rod Elements," Molten-Salt Reactor Program Semiann. Progr. Rept. Jan. 31, 1962, ORNL-3626, pp. 76-78.

⁵"Sintering Characteristics of Gd₂O₃-Al₂O₃," Molten-Salt Reactor Program Semiann. Progr. Rept. July 31, 1963, ORNL-3529, p. 78.

⁶V. A. DeCarlo, F. R. McQuilkin, and R. L. Senn, "Fuel Element Irradiation Tests," Medium-Power Reactor Experiment Quart. Progr. Rept. Sept. 30, 1964, ORNL-3748, pp. 57-58 (classified).

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Fig. 3. Component Parts for the MPRE Fuel Elements. A, brazed subassembly; B, $Gd_2O_3-Al_2O_3$ pellets; C, BeO pellets; D, MgO pellets; E, upper end cap; F, assembly of upper end cap and spring plunger; H, plunger; and J, lower end cap.

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Fig. 4. A group of Production UO_2 Pellets Used in the MPRE Fuel Elements.

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components, and Table 1 lists them, the methods of manufacture, the manufacturers, and the inspections performed on each. Chemical analyses, mechanical properties, and suppliers for the metal components are given in Tables 2, 3, and 4.

Type 316H stainless steel seamless tubing for the cladding was manufactured under very exacting conditions. Since the clearance between the UO_2 pellets and the cladding was important for heat transfer, the tubing was given complete dimensional inspection, including a resonance-ultrasonic test for wall thickness. All tubing was inspected for internal flaws by ultrasonic methods. Visual and dye-penetrant inspection methods were used to locate external flaws. The spacers were punched from type 316H stainless steel sheet, and the remaining stainless steel parts were machined from bar stock with full certification to ASTM specifications plus inspection by ultrasonic and dye-penetrant methods. After being machined and dimensionally checked, the finished parts were given another dye-penetrant inspection.

The TZM alloy spring was formed from wire that had been inspected by eddy-current methods. The finished spring was inspected dimensionally and by dye-penetrant methods.

The UO_2 powder for the fuel was converted from UF_6 and pelletized by conventional cold pressing methods.⁷ The manufacturing parameters used for the reactor fuel pellets could not be used for the prototype because sintering characteristics of the two oxides differed. Table 5 compares the manufacturing parameters for these two types of pellets.

The reactivity of the highly enriched batch of UO_2 was so low that high pressing pressure was needed to attain high density. The high pressing pressure produced a condition in the early pellets called "capping." This condition is characterized by one or more transverse cracks that extend inward along a plane perpendicular to the axis near the top of the pellet. The capping condition was not acceptable because

⁷J. Belle (ed.), Uranium Dioxide Properties and Nuclear Application, U. S. Atomic Energy Commission (1961).

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Table 1. Manufacture Methods and Inspection Performed on MPRE Fuel Element Components

Component	Type Material	Method of Manufacture	Inspection Methods								Certification to Standards Other than NRS	Manufacturer
			Penetrant Inspection of Raw Stock	Ultrasonic Inspection of Raw Stock	Penetrant After Machining or Forming	Dimensional Inspection	Density	Visual	Chemical Analysis	Other		
Tubing	Type 316H stainless steel	Drawn	X	X		X	X	X	Resonance ultrasonic	ASTM-213	Superior Tube Co.	
Pellets	UO ₂	Pressed and sintered					X	X	X	BET, dryness	Westinghouse ^a	
Pellets	MgO	Pressed and sintered					X	X	X		DU-CO Ceramics Co.	
Pellets	BeO	Pressed and sintered			b		X	X	X		Brush Beryllium Co.	
Pellets	Gd ₂ O ₃ -Al ₂ O ₃	Pressed and sintered					X	X	X	Thermal cycle	Westinghouse, APD	
End caps and plunger	Type 316H stainless steel	Machined from bar	X	X	X	X	X	X		ASTM-276	Vallorbs Jewel	
Spacers	Type 316H	Stamped from sheet						X	X	ASTM-276		
Spring	TZM	Formed from wire			X			X	X	Eddy current ^b	General Electric Co. (wire) C & M Machine Co. (winding)	
Tube sub-assembly	Type 316H Nicro-braze 50	Hydrogen braze				X	X		Process control		Aerobraze Co.	

^aPellets pressed by Westinghouse from UO₂ supplied by Nuclear Fuel Services.

^bNot required by specification but performed by the manufacturer.

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Table 2. Chemical Analyses of Type 316H Stainless Steel Used
in the MPRE Fuel Elements

Element	Content, %					
	Tubing ^a		Bar ^b		Spacers (Ladle Only)	
	Ladle	Check	Ladle	Check	Heat 21986 ^c	Heat 71372 ^d
<u>Required Analyses</u>						
C	0.05	0.06	0.055	0.07	0.056	0.040
Mn	1.70	1.74	1.77	1.90	1.56	1.55
P	0.019	0.018	0.028	0.013	0.018	0.022
S	0.010	0.011	0.024	0.030	0.010	0.012
Si	0.56	0.59	0.43	0.45	0.41	0.48
Ni	13.60	13.37	12.49	12.53	12.40	12.84
Cr	17.17	17.05	17.63	17.44	17.45	17.38
Mo	2.24	2.26	2.30	2.16	2.65	2.11
Co	0.068	0.090	0.12	0.08		0.03
<u>Other Analyses</u>						
B	0.0009		0.0001			
Cu			0.38	0.29	0.16	0.16

^aSuperior Tube Company heat 27723X.

^bJoslyn stainless steel heat 46859. End caps and plungers fabricated from this stock.

^cAllegheny Ludlum Steel Company.

^dUlbrich Stainless Steel, Inc.

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Table 3. Chemical Analyses of TZM Alloy for MPRE
Fuel Element Springs^a

Element	Content, %					
	Heat 6123		Heat 6003		Heat 1155B	
	Ladle	Check	Ladle	Check	Ladle	Check
<u>Required Analyses</u>						
C	0.017	0.0186	0.018	0.0134	0.016	0.0161
Si	0.003	0.0015	0.001	0.0017	0.0035	0.0064
Ni	0.001	0.001	0.001	0.001	0.002	0.001
<u>Other Analyses</u>						
Fe	0.002	0.0041	0.001	0.002	0.0015	0.0016
Ti	0.50	0.40	0.55	0.46	0.46	0.50
Zr	0.07	0.115	0.09	0.087	0.09	0.092
O	0.0008	0.0049	0.0008	0.0059	0.0018	0.0058
N	0.0007	0.0024	0.0013	0.0017	0.0001	0.0025
H	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001

^aSupplied by General Electric Company.

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Table 4. Mechanical Properties of Metal Components Used
in the MPRE Fuel Elements

Material	Heat	Supplier	Component	Strength, psi		Elongation (%)	Hardness
				0.2% Yield	Ulti- mate		
Bar	46859	Joslyn Stainless Steel	End caps Plungers	66,250	87,500	58.9	RB 90
Tubing	27723X	Superior Tube Company	Cladding:				
			Ladle	42,700	89,000	58.0	B 69/70
			Check	42,600	87,000	58.0	B 69/69
Sheet	21986	Allegheny Ludlum Steel	Spacers	37,040	83,990	55.0	T 30/68
Sheet	71372	Ulbrich Stainless Steel	Spacers				RB 71
TZM	6123	General Electric Corp., Dover, Ohio	Springs	133,500	139,500	18-20	
				to 143,200	to 149,200		

Table 5. Fuel Pellet Manufacturing Parameters.

	Prototype, 7% Enriched	Reactor, 93% Enriched
Presinter temperature, °C	775	775
Presinter time, hr	23	23
Presinter atmosphere	CO ₂	CO ₂
Pressing pressure, psi	64,000	108,000
Sintering temperature, °C	1650	1750
Sintering time, hr	15	16
Sintering atmosphere	H ₂	H ₂
Binder and lubricant	1% Carbowax and 1% Poly(vinyl alcohol)	1% Carbowax and 2% Poly(vinyl alcohol)
Grinding lubricant	Water	Water

it increases the chances that small chips may form. These chips could wedge between the pellets and the cladding and interfere with free thermal expansion of the UO₂ column. To eliminate this condition, a 10-mil chamfer was rubbed or sanded around the top edge of the green pellet. This chamfer also reduced the amount of normal pellet chipping. The finished pellets show very little chipping or cracking, as can be seen in Fig. 4. Chemical analyses and density checks were made on each batch of pellets, and a BET surface area test was run on some. Table 6 lists the results. In addition, a dryness test, described in Appendix C, Procedure 1, was run.

The BeO and Gd₂O₃-Al₂O₃ pellets were cold pressed and sintered. As an added protection, the vendor inspected the BeO pellets by dye penetrant. As a proof test, each of the Gd₂O₃-Al₂O₃ pellets was quenched in water from 1475°F before inspection, as described in Appendix C, Procedure 2. The MgO was extruded into a rod, centerless ground to size, and sliced into pellets. Surprisingly, the MgO pellets were the most difficult items to obtain. After three attempts, one vendor still could not fabricate pellets that would meet the required analyses. The

Table 6. Chemical and Physical Analyses of UO₂ Pellets

Batch	Analyses Made By	Uranium (%)	O/U	Impurities, ppm												Average Density (% of theo- retical)	BET Surface Area (cm ² /g)
				C	N	Al	Ca	Fe	Si	F	Cr	Cu	Mg	Mn	Na		
A-01	WAPD	88.13	2.008	<10	19	33	30	56	15							94	
A-01	WAPD	88.11	2.003	<10	20	24	43	56	15							95	
A-01	ORNL	88.58	2.001	<20	125	6		105	80	6	1	1	3	1	20		
A-02	WAPD	88.14	2.002	<10	19											95	
A-02	WAPD	88.11	2.003	<10	22											95	
A-02	ORNL	88.73	2.001		65	5		89	135	3	1	5	3	1	20		
A-03	WAPD	88.04	2.017	<10	18											95	
A-03	WAPD	88.03	2.016	<10	18											96	
A-03	ORNL	87.71	2.001	<20	105	8		144	160	7	8	1	3	2	30		
A-04	WAPD	88.09	2.004	<10	14											95	
A-04	WAPD	88.11	2.003	<10	17											95	
A-04	ORNL	87.80	2.001	<20	50	9		115	118	8	9	4	4	2	30		
A-05	WAPD	88.12	2.012	<10	43											95	
A-05	WAPD	88.11	2.003	<10	40											95	
A-05	ORNL	87.70	2.001	<20	50	6		161	130	4	6	3	6	1	6		
A-06	WAPD	88.13	2.007	140	43											95	
A-06	WAPD	88.09	2.004	300	40											97	
A-06	ORNL	87.91	2.001	<30	55	50		111	87	11		5	1		5		
A-07	WAPD	88.09	2.003	<10	35											96	
A-07	WAPD	88.09	2.002	<10	35											96	
A-07	ORNL	87.78	2.001	<30	40	3		94	91	6	2	6	3	3	5		2.0
A-08	WAPD	88.05	2.006	<10	16											94	
A-08	WAPD	88.09	2.003	<10	25											95	
A-08	ORNL	87.96	2.001	<20	60	5		107	71	4	1	5	2	2			
A-09	WAPD	88.08	2.009	<10	15											95	
A-09	WAPD	88.09	2.001	<10	15											96	
A-09	ORNL	88.73	2.001	<30	30	10	65	84	11	<1		11					
A-10	WAPD	88.04	2.003	<10	19											96	
A-10	WAPD	88.08	2.004	<10	14											96	
A-10	ORNL	88.22	2.001	<20	26	7.7	51	84	9	<1		2					

Table 6 (continued)

Batch	Analysis Made By	Uranium (%)	O/U	Impurities, ppm												Average Density (% of theo- retical)	BET Surface Area (cm ² /g)
				C	N	Al	Ca	Fe	Si	F	Cr	Cu	Mg	Mn	Na		
A-11	WAPD	88.06	2.006	<10	18											96	
A-11	WAPD	88.05	2.003	<10	21											96	
A-11	ORNL	88.15	2.001	<20	38	33	110	120	11	<1		110 ^a					2.0
A-12	WAPD	88.06	2.003	<10	22											95	
A-12	ORNL	88.19	2.001	<20	50	10	63	112	11	<1		340 ^a					1.4
A-13	WAPD	88.01	2.003	<10	16											96	
A-13	ORNL	87.80	2.001	<20	44	3.7	18	427	8	<1		<1					3.0
A-14	WAPD	88.01	2.008	<10	20	30	51	52	<15							96	
A-14	ORNL	87.09	2.001	<20	33	11	25	99	15	5		<1					2.7
A-15	ORNL																3.0
A-16	ORNL																3.0
A-17	ORNL																3.0
A-18	ORNL																2.0
A-19	ORNL																2.0
A-24	WAPD	87.97	2.005	<10	28	34	21	53	21							94	
A-24	WAPD	87.92	2.002	<10	20												
A-24	ORNL	88.40	2.001	<20	32	28	94	80	12	<1		2100 ^a					

^aIn excess of that allowed by the specification but accepted on waiver.

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purchase order was then placed with DU-CO Ceramics Company, who made the EGCR fuel pellets. DU-CO made acceptable pellets on the first try. Because of scheduling problems, the MgO pellets for the prototype were EGCR pellets machined to proper size. Table 7 lists some of the more important data on the BeO, MgO, and Gd₂O₃-Al₂O₃ pellets.

Table 7. Data on Nonfuel Ceramics

Material	Magnesium Oxide	Beryllium Oxide		Gd ₂ O ₃ -Al ₂ O ₃
Supplier	DU-CO Ceramics Co.	<u>Brush Beryllium Co.</u>		a
Blend batch	1	J-19-1	J-20-1	2
Density, g/cm ³	2.2	2.8-2.93	2.88-2.93	>5.6
Analysis, ppm				
B	8	<1	<1	
SiO ₂	2000	190	320	
CaO	2000	250	250	
Fe ₂ O ₃	300	70	70	
PbO	10			
Al ₂ O ₃	800	1700	2000	
CuO	10			
TiO ₂	20			
NiO	10			
MnO	50			
Cr ₂ O ₃	10			
C	100			
S	40			
Analysis, %				
BeO		99.7	99.7	
Gd ₂ O ₃				70.33, 70.84

^aFabricated by Westinghouse using Gd₂O₃ powder obtained from American Potash and Chemical Corporation.

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ASSEMBLY OF THE FUEL ELEMENTS

Except for brazing, the fuel elements were assembled in a classified area at Westinghouse-APD Research Laboratory, Cheswick, Pennsylvania. They were brazed at Aerobrazo in Cleveland, Ohio. After brazing, all of the assembly and inspection was performed by security-cleared personnel.

Welding techniques were carefully worked out by making a number of sample welds and evaluating the results. The final procedures were then qualified by making three welds of each type. These welds were sectioned to ensure a crack-free weld with a minimum penetration of 0.020 in. In appendix C, procedures 3 and 4 give the procedures for each weld. When there were several days delay in production welding, Westinghouse made test welds, which were sectioned and evaluated to ensure conformance with the specifications, before production welding was resumed. After the fuel elements were completed, the ORNL inspector selected 3 elements out of each 100 and these were sectioned to check their conformance with the specifications. A section through the top end cap of a production assembly is shown in Fig. 5.

The first assembly operation was the insertion of a bottom end cap into the fuel tube. The end cap was designed to have a slight interference fit with the tube to facilitate welding. The weld was made automatically, as is shown in Fig. 6. A record of the voltage and current was maintained for each weld.

Next, the spacers were attached. They were held by a fixture while being spot welded in place. The design of a fixture to ensure proper spacing proved to be difficult. After the original fixture was modified a number of times, a new one was designed and built that maintained proper alignment (see Fig. 7). Spot welding was carefully controlled to prevent damage to the wall of the tube. Even after careful qualification, 1 tube out of every 100 was sectioned and examined to ensure that the tube wall had not been damaged. After preplacing the Microbraz 50, the brazing was performed in a retort at a temperature near 1900°F but under 1925°F for a period not exceeding 27 min. Originally, we intended to hold the brazing cycle under 20 min, but some assemblies needed

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Fig. 5. Section Through the Top End Cap Showing the Closure Welds on the MPRE Fuel Element. 10X.

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Fig. 6. Welding the Bottom End Cap into the Tube.

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Fig. 7. Fixtures and Gages Used in the Manufacture of the MPRE Fuel Elements. A, fixture used to check element straightness and concentricity; B, fixture used to hold spacers in place for spot welding; C, air gage for checking the inside diameter of the element; D, dial indicator, E, calibration block, and F, positioning fixture for checking the height of the spacer off the tube; G and H, no-go gages for outside diameter of spacer clusters; H is notched to slip over the outer clusters for checking the center cluster; I and J, air-gage calibration blocks; K, clamp used with fixture B; L, go no-go gage used to check separation between spacers; and M, fixture used to check height of lower end cap stem from lower end cap weld.

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rebrazing. The longer braze cycle was carefully evaluated, and no appreciable increase in grain size was noted. The brazing operation is described in Appendix C, Procedure 5. A sample braze from the furnace run was sectioned and examined for grain size, as shown in Fig. 8. After each cluster of spacers was machined to the proper outside diameter, the brazed assembly was given a final dimensional inspection as follows:

1. An air gage was used to check the inside diameter of the tubing under each spacer cluster.
2. A go no-go gage was used to check the outside diameter of the spacers.
3. One line of spacers was checked to ensure that all spacers were in line and in proper orientation with the hole in the lower end plug.
4. A go no-go check was made between adjacent spacers in a cluster.
5. A go no-go check was made on the height of each spacer above the outer surface of the tube.
6. The tube was checked for straightness.

Figure 7 shows some of the gages used in this inspection. Figure 9 shows the spacers brazed in place on the prototype elements.

The stack of pellets, as shown in Fig. 10, was then selected to meet the weight and length requirements of the specification. Figure 11 gives the distribution of the stack lengths and weights for all the fuel elements. The stack lengths and weights and the lot numbers of all the components were recorded on Form 1, shown in Appendix C. The pellets were loaded into the tube, as shown in Fig. 12, and the top edge fusion weld was made. The loaded elements were placed in a cluster of tubes in a drying retort; the retort was placed in a furnace, as shown in Fig. 13, heated to 480°F, and evacuated for a minimum of 4 hr. The retort was then cooled, removed from the furnace, and sealed to the dry box (see Fig. 14) in which the final closure weld was to be made. Next, the dry box was evacuated, the retort was opened into the dry box, and both the dry box and the fixture were filled with helium. The dryness of the pellets was checked by Procedure 6 in Appendix C. Figure 15 shows an overall view of the dry box with the drying fixture in place.

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Fig. 8. Section Through Brazed Spacer on MPRE Fuel Element. 39X.

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Fig. 9. Brazed Spacers Shown on the Four Prototype MPRE Fuel Elements.

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Fig. 10. A Stack of Pellets with Spring and Plunger Ready to Be Loaded into an MPRE Fuel Element.

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Fig. 11. Distribution of the Stack Lengths and Weights for the MPRE Fuel Elements.

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Fig. 12. Loading a Stack of Pellets into an MPRE Fuel Element.

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Fig. 13. Drying Retort Half Way in the Furnace. The MPRE elements are inside the cluster of tubes at the back of the retort.

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Fig. 14. The Drying Retort is Sealed to the Dry Box Where the Final Closure Weld was Made.

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Fig. 15. Dry Box Where the Final Closure Welds on the MPRE Fuel Element Were Made.

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The element was positioned for welding by use of the dry-box gloves. The glove ports were then closed so that the dry box could be evacuated to 0.5 atm and the final weld could be made, as shown in Fig. 16. This process of positioning the fuel element with the gloves, closing the glove port, and evacuating was repeated until all the elements in the retort had been welded. Use of this procedure ensured that the pellets were never exposed to a moist atmosphere after drying.

INSPECTION OF THE ASSEMBLED FUEL ELEMENT

Each phase of inspection of the fuel element was recorded on Form 1, shown in Appendix C. The fuel elements were leak checked immediately after removal from a helium atmosphere by comparing the amount of helium released by a standard leak of 7×10^{-9} cm³/sec with the helium released by the elements. One of the elements showed a leak of about 10^{-7} cm³/sec in the final closure weld. No other nondestructive device detected this leak. Although the weld was repaired and did not leak on reinspection, the element was scrapped, and metallographic sections were taken through the weld. No evidence of cracking was found in the weld, and the only possible explanation for the leak was a long oxide stringer found adjacent to the weld in the end cap.

The welds were inspected by the postemulsification fluorescent penetrant process. Since the penetrant process can conceal small leaks, it was always preceded by the leak test. The edge fusion welds used on the element caused the same problem in interpretation of penetrant indications by entrapment of penetrant in the area where the weld bead rolled down on the tube or end cap. Each of the welds that showed this "roll-over indication" was evaluated and approved by an ORNL inspector.

The welds were x-rayed by procedures developed by the ORNL Inspection Group working with Westinghouse personnel (see Appendix C, Procedure 7). After visual inspections, the following dimensions were checked:

1. Overall length.
2. Straightness and concentricity (with Fixture A in Fig. 7).

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Fig. 16. The MPRE Fuel Element in Dry Box Ready for the Final Closure Weld.

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3. Height of the lower end cap stem above the weld (with Fixture M in Fig. 7).
4. Weld buildup (roll over).

In addition, the proper spacer location on the brazed subassembly was checked on 10% of the elements. The overall element was then x-rayed to check for proper location of all the components and to find any handling damage. Figure 17 shows a radiograph of one of the prototype fuel elements. The final inspection step at Westinghouse was a visual inspection just before the elements were placed in the shipping containers.

Five fuel elements were accepted that had very slight dents at the top of the tube near the top closure welds. Three more fuel elements were accepted that contained weld porosity at the size limit allowed by the specifications.

CONCLUSION

Upon arrival at the Y-12 area in Oak Ridge, the fuel elements were inspected for shipping and handling damage with a 1-Mev x-ray machine. Although some pellets showed signs of additional cracking, no rejectable damage was found. By the methods described in this report, 300 MPRE fuel elements were successfully produced.

ACKNOWLEDGMENT

I wish to thank the many people at Westinghouse Atomic Power Department, Cheswick, Pennsylvania, for the cooperation extended to us and to the management of APD for giving their permission to make and to use the photographs in this report. Particularly, I would like to thank R. Duncan and M. A. Parker of APD, Project Engineer and Quality Control Engineer, respectively, on the MPRE fuel elements.

In writing this report, I have drawn on the work of many people at ORNL and Y-12. Many people helped in preparing and commenting on the specifications. A special acknowledgment to G. Samuels, who designed the fuel element and was always available to consult on the many

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SPRING & PLUNGER↑
 $Gd_2O_3-Al_2O_3$ ↑PELLET ↑B.O. PELLETS
↑ UO_2 PELLETS↑
 MgO ↑PELLET

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problems that arose during the manufacture of the reactor core.

Mr. Samuels filled in for me when I was away and made trips to Westinghouse to evaluate the manufacturing process.

The ORNL Inspection Engineering Department did their usual efficient job in following the inspection of this core. I would particularly like to acknowledge the work of J. C. Dedrick, the ORNL resident inspector, who not only did a fine job of being ORNL's eyes and ears at the vendor's plant, but he also aided me in expediting the job and on many occasions helped Westinghouse in the manufacture and inspection of the core.

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APPENDIX A

Specifications

These specifications have been revised to reflect the as-built condition of the MPRE fuel elements. All revisions are marked with an R in the right-hand margin. In various places in the specifications insertions were added to give deviations from the specifications and to add additional data. These insertions are set off by parentheses and are marked by an I in the right-hand margin.

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September 17, 1964

INTRODUCTION

The specifications NRS-1 through NRS-10 define the fuel element for the MPRE (Medium Power Reactor Experiment). The master assembly specification is classified, while the specifications for components are not. This was done so that the prime contractor (Seller) could have components made by subcontractors on a nonclassified basis. It is the Seller's responsibility to see that none of the components can be in any way related to the MPRE. All Seller's personnel (Procurement, Accounting, Manufacturing, etc.) handling this contract must have a "Q" clearance or "L" clearance for similar information. All records of procurement, accounting, manufacturing, etc., which can be related to the MPRE must be classified. The elements are to be assembled in a restricted area. The Seller shall not solicit bids on more than two specifications from any noncleared subcontractor.

Items required will be as follows:

1. A quotation based on production of 296 fuel elements in accordance with NRS-1 through NRS-10. R
2. One hundred and sixty (160) 7% enriched UO_2 pellets in accordance with NRS-3. R
3. Ten pieces of tubing and two feet of 316 H bar, in accordance with NRS-2 and NRS-7, respectively. The bar shall be the material used to machine end caps.
4. Four prototype fuel elements made in accordance with NRS-1 through NRS-10, except that the lower end cap will be modified in accordance with Dwg. A-108-89, "Prototype End Cap", and 7% enriched UO_2 will be used for the pellets.

It is important that these parts be processed as nearly the same as the fuel element as possible. The dates required are very important because of test reactor scheduling. The Company will furnish 156 kg of UF_6 for the manufacture of item one and 5.22 kg of UF_6 for the manufacture of items two and four.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-1
Date: September 17, 1964
Rev. No: 1
Page: 1 of 13

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

I. SCOPE:

This specification defines fuel elements consisting of a column of ceramic pellets encased in type 316H stainless steel tubing sealed to top and bottom end caps by welding. The ceramic pellet column consists of a MgO spacer, a stack of UO_2 pellets, a stack of BeO pellets, topped by a Gd_2O_3 -30% Al_2O_3 pellet. A plunger and spring are provided at the top of the fuel element in order to keep the column of ceramic pellets in compression. The fuel element shall contain an inert environment of 1/2 atmosphere of helium. Three sets of six spacers are provided on the outside of each element.

II. MANUFACTURING REQUIREMENTS:

- A. The fuel elements shall be manufactured in accordance with Dwg. C-108-80, "Assembly, Fuel Element," and in accordance with this specification.
- B. The final closure weld shall be made in an atmosphere that contains a minimum of 95% helium by volume at 6 to 8 lbs/sq in. absolute pressure. The pressure shall be checked and recorded using a mercury manometer before and after welding.
- C. The column of ceramic pellets shall be dried at 250°C for four hours at a pressure not to exceed 100μ. It is required that the column be sealed after drying without the pellets being exposed to air.
- D. All completed fuel elements shall be cleaned to remove traces of nuclear contamination in excess of 10^{-8} g/cm².
- E. Each fuel element is to be given an identifying three digit Arabic number (001, 002, 003, ...) . The number shall be marked on each fuel element by means of an electrolytic etch. The number shall be etched onto the tube before the spacers are attached and all records on that tube or fuel element shall refer to its identifying number.
- F. The Gd_2O_3 - Al_2O_3 pellets shall be degassed at a temperature of R not less than 1600°F for one hour. This operation should be performed as near the loading time as is practical. After degassing, the pellet should be stored in a dry helium atmosphere.

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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

III. REFERENCES:

A. Specifications

1. NRS-2, "Specification for Tubing"
2. NRS-3, "Specification for Uranium Dioxide Pellets"
3. NRS-4, "Specification for Magnesium Oxide Pellets"
4. NRS-5, "Specification for Beryllium Oxide Pellets"
5. NRS-6, "Specification for Gadolinium Oxide-Aluminum Oxide Pellets"
6. NRS-7, "Specification for End Caps and Plungers"
7. NRS-8, "Specification for Springs"
8. NRS-9, "Specification for Tube Subassemblies"
9. NRS-10, "Specification for BET Surface Area"
10. ASTM Designation: E 142 - 59 T, "Tentative Method for Controlling Quality of Radiographic Testing"
11. ASTM Designation: E 2 - 49 T, "Methods of Preparation of Micrographs of Metals and Alloys"
12. ASTM Designation: E 3 - 58 T, "Methods of Preparation of Metallographic Specimens"
13. MET-NDT-4, Rev. 3, "Tentative Method of Liquid Penetrant Inspection"

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B. Drawings

1. C-108-80, "Assembly, Fuel Element"
2. B-108-79, "Tube"
3. B-108-81, "Subassembly, Tube"
4. A-108-76, "End Cap (Upper)"
5. A-108-75, "End Cap (Lower)"
6. A-108-82, "UO₂ Pellet"
7. A-108-83, "MgO Pellet"
8. A-108-84, "BeO Pellet"
9. A-108-85, "Gd₂O₃ - Al₂O₃ Pellet"
10. A-108-77, "Plunger"
11. A-108-78, "Spring"
12. A-108-86, "UO₂ Weight-Length Tolerance"

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IV. MATERIALS:

Each fuel element shall consist of the following components:

<u>Component</u>	<u>Drawing No.</u>	<u>Spec. No.</u>
Tube	B-108-79	NRS-2
Tube Subassembly	B-108-81	NRS-9
Upper End Cap	A-108-76	NRS-7
Lower End Cap	A-108-75	NRS-7
Plunger	A-108-77	NRS-7
UO ₂ Pellet	A-108-82	NRS-3
MgO Pellet	A-108-83	NRS-4
BeO Pellet	A-108-84	NRS-5
Spring	A-108-78	NRS-8
Gd ₂ O ₃ - Al ₂ O ₃ Pellet	A-108-85	NRS-6

After completion of the fuel element, the condition of the components shall conform to the requirements specified in the referenced specifications.

V. FUEL ELEMENT LOADING:

- A. The total length and weight of the column of uranium dioxide fuel pellets shall be in accordance with Dwg. A-108-86, "UO₂ Weight-Length Tolerance".
- B. The total length and weight of the column of beryllium oxide pellets shall be in accordance with Dwg. C-108-80, "Assembly, Fuel Element".
- C. The total length of the column of ceramic pellets shall be in accordance with Dwg. C-108-80, "Assembly, Fuel Element".
- D. The numerical values for Items V - A, B, and C shall be recorded for each fuel element and submitted to the Company.

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A Division of Union Carbide Corporation
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V. FUEL ELEMENT LOADING: (Cont'd)

- E. A sample of 3% of the fuel elements shall be checked for nuclear contamination by a method to be approved by the Company. The test shall be made just before shipment of the completed fuel elements. If the contamination is greater than 10^{-8} g/cm³, all of the fuel elements represented by the sample must be cleaned and retested.

VI. WELDING REQUIREMENTS:

- A. The end caps shall be joined to the fuel element tube by means of an edge fusion weld made by the Gas Tungsten Arc process. The final closure weld shall be made by fusing the 0.040-in. hole in the upper tube end cap.
- B. All welds shall have a minimum of 0.020-in. penetration.
- C. The welding procedure shall be submitted to the Company for approval.
- D. No production welding shall be performed before the welding procedure has been qualified and approved.
- E. The welding procedure shall be qualified by making three welds of each type.
- F. The welding parameters on the qualification test shall be set to give the minimum penetration with the range of parameters allowed in the procedures.
- G. Qualification welds shall be inspected in accordance with this specification.
- H. All qualification edge fusion welds shall be sectioned by the Seller longitudinally through the weld area at approximately 90° intervals, thus permitting four penetration measurements on each weld. (One section shall be made at the location where welding was stopped.) The final closure weld shall be sectioned at its midpoint. The sections shall be prepared for examination, metallographically measured, and photographed as specified in ASTM Designations: E 2 - 49 T and E 3 - 58 T unless otherwise specified in this specification. The photographs shall become the property of the Government and shall be delivered with or prior to final shipment.

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VI. WELDING REQUIREMENTS: (Cont'd)

1. The sections shall be free of cracks.
2. The sections shall be free of voids, porosity, or inclusions greater than 0.005-in. in their largest dimensions.

VII. LEAK TEST:

- A. Each fuel element shall be helium-leak tested before penetrant inspection is performed. Helium-leak testing shall be carried out in accordance with the following procedure:
1. Scope. - This section applies to the bell-jar method of testing the assembled, helium-containing fuel elements after the final closure weld has been accomplished.
 2. Reference. - The Manufacturer's operating manual for the particular instrument shall be used in the inspection.
 3. Equipment. - The equipment shall be a mass-spectrograph type, helium-sensitive instrument, similar to the Veeco Type MS-9 or Consolidated Engineering Corporation Type 24-110, which includes the following as incorporated in the instrument or as additions or modifications:
 - a. A cold trap (liquid nitrogen or liquid air).
 - b. A helium-leak source of 7×10^{-9} std cc/sec.
 - c. An external or auxiliary roughing vacuum pump connected to the instrument manifold and to the specimen or test chamber through a vacuum valve.
 - d. A throttling or modulating valve between the instrument manifold and the instrument.
 - e. A low-pressure supply of helium with a nozzle less than 1/16-in. in diameter for use in checking for leak-tight connections.
 - f. One or more leak-tight chambers, each of which is capable of accommodating a fuel element for the final closure weld inspection and having no less than 3/8-in. diametrical clearance between the fuel element and the wall of the chamber.

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VII. LEAK TEST: (Cont'd)

4. Technical Requirements. -

- a. The instrument sensitivity shall be such that the stable signal from the standard leak, as determined in Section VII-A-5-c of this specification, is at least two times as large as the signals produced by background noise.
- b. The inspection shall be performed in a force-ventilated location to facilitate the removal of any helium background.
- c. The connecting lines between the test chamber and the instrument manifold shall be as short as is practical and should have a minimum inside diameter of 1/2-in. All connections shall be leak-tight.
- d. Care shall be exercised to avoid plugging leaks with any sealant prior to attempted detection with helium.
- e. All assembled fuel elements shall be either helium-leak tested within 48 hours after the final closure weld is completed or stored in a helium atmosphere of pressure equal to or greater than the internal pressure of the fuel element until such time as they can be helium-leak tested. If a fuel element is to be retested or if the testing procedure is interrupted, as in Section VII-A-5-a, -f, and -g of this specification, the fuel element shall be stored in a helium atmosphere as described until such time as testing can be completed. No assembled fuel element shall be allowed to remain in a nonhelium atmosphere for more than a total of 48 hours between the time of its assembly and the completion of helium-leak testing.

5. Testing Procedure. -

- a. The performance of the leak-detector equipment shall be verified after each inspection. If at any time this equipment fails to function properly as described in the Manufacturer's operating manual, and/or if the sensitivity as determined in Section VII-A-5-c of this specification decreases below the minimum level prescribed in Section VII-A-4-a, the equipment shall be readjusted to function as specified and recalibrated, and all fuel elements which have been inspected during the interim since the last satisfactory performance verification of the equipment shall be inspected again.

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VII. LEAK TEST: (Cont'd)

- b. The fuel element shall be inspected as follows: The assembled, helium-containing fuel elements shall be inspected after the final closure weld has been accomplished by placing the fuel element in the inspection chamber, evacuating the chamber, and searching for helium leaks as prescribed in the instrument Manufacturer's operating manual.
- c. The instrument shall be calibrated as follows: The standard leak source (7×10^{-9} std cc/sec) shall be connected to one end of the test chamber. The opposite end of the test chamber shall be connected to the manifold, and the time which is required to produce a signal two times as large as the background noise shall be measured. This measurement shall be accomplished while examining a 100% sample from the test chamber and with all valves between the standard leak source and the helium-sensing device completely open. This portion of the calibration shall be continued until the signal from the standard leak reaches a stable amplitude. The signal amplitude and manifold pressure shall be measured at this point.
- d. The inspection shall be made taking a sample from the test chamber. All valves between the fuel element and the helium-sensing device shall be completely open and the time of inspection shall be no less than one minute and at least twice as long as the time, as determined in Section VII-A-5-c of this specification for that particular method, required for the standard leak to produce a signal two times as large as the background noise.
- e. The manifold pressure at which the inspection is made shall be the same as the pressure at which the instrument is calibrated, as measured in Section VII-A-5-c of this specification.
- f. Excessive pump-down time shall be indicative of an external leak. The leak shall be located and corrected before further testing is accomplished.
- g. During the inspection, any signal which produces an indication two times as large as the background noise level shall be indicative of a through path or leak in the element being inspected and that fuel element shall be rejected. If more

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VII. LEAK TEST: (Continued)

than one assembled fuel element is being inspected at the time a leak is detected, the fuel elements shall be inspected again such that the leaking fuel element or fuel elements are identified and rejected.

- h. All rejected, assembled fuel elements shall be disassembled. Any salvageable parts of the rejected fuel elements may be reused in the assembly of other fuel elements. A salvageable item is one that is reinspected and found to conform to the specification.

VIII. PENETRANT INSPECTION OF ELEMENT:

Each fuel element weld shall be 100% examined for discontinuities by means of penetrant inspection in accordance with MET-NDT-4, Rev. 3. The process times shall be that listed in Table 2 of MET-NDT-4 for "All forms with machine finish 125 rms or better." The penetrant inspection shall be performed after the elements are leak tested.

IX. VISUAL INSPECTION:

- A. Each fuel element will be given a careful visual inspection by a qualified inspector under lighting of 100 foot candles just prior to shipment.
- B. Any visual indication questioned by the Company's inspector must be removed. If the fuel element will not meet any provision of the specification after removal of the indication, the fuel element shall be rejected. After removal of the indication, the fuel element shall be completely inspected.
- C. Each weld shall be smooth, bright, and free of contamination as determined by visual inspection.
- D. Each weld shall be free of surface cracks, surface porosity, or craters.

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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

X. RADIOGRAPHIC EXAMINATION OF WELDS:

Each weld shall be examined using a radiographic technique that is consistently capable of detecting discontinuities of 0.005-in.-max. dimension. Radiographic technique shall be capable of allowing a complete evaluation of the entire weld area.

- A. A minimum acceptable demonstration shall be the visible image of a 0.005-in.-diam. hole in a 0.005-in.-thick penetrameter. In addition, the penetrameter shall contain holes of 0.010 and 0.0025-in. diam.
- B. The Seller shall submit to the Company for approval their procedure for radiographing all of the welds on the fuel element. The procedure shall include sample radiographs for each weld made by the Seller's procedure.
- C. All other radiographic requirements shall be in accordance with the recommendations of ASTM Designation: E 142 - 59 T, "Controlling Quality of Radiographic Testing".
- D. Any porosity greater than 0.010-in. or any cracks shall reject the weld.
- E. All radiographs are to become the property of the Government.

XI. DESTRUCTIVE TEST OF WELDMENT:

- A. A sample of 3% of the fuel elements will be selected by the Company's inspectors. The sample may be selected immediately after welding or after all nondestructive testing has been performed at the Seller's option.
- B. All the welds on the fuel elements selected for test shall be sectioned, examined, and photographed in accordance with Section VI-H of this specification. The photographs and sectioned samples shall become the property of the Company and shall be delivered with or prior to final shipment.
- C. The sections shall be free of cracks. The sections shall be free of porosity or other inclusions greater than 0.005-in. in their dimensions.

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XI. DESTRUCTIVE TEST OF WELDMENT: (Continued)

- D. The welds shall show a minimum of 0.020-in. penetration on all sections.
- E. If one or more fuel elements of the 3% random sample are rejected, then a double number of fuel elements shall be selected for testing. If one or more of the second group are determined to be rejectable, then the entire lot shall be considered rejectable and the Seller shall be responsible for initiation of corrective action. After initiation of corrective action, sampling shall again go into effect as described above.

XII. DIMENSIONAL INSPECTION:

- A. Each fuel element shall be inspected to determine the outside diameter at the weld and the length using go and no go gage.
- B. Each fuel element shall be checked for straightness.
- C. One out of every 10 finished fuel elements shall be checked for OD spacer dimension in accordance with NRS-9 Section VII-A-2.
- D. The gages shall become the property of the Government.
- E. Any reworking performed on the fuel element to pass the above test must be approved by the Company.

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XIII. RADIOGRAPHIC EXAMINATION OF FUEL ELEMENT:

- A. As a final check, each fuel element shall be radiographed to check for proper assembly and to inspect the ceramic pellets for handling damage.
- B. The Seller shall submit to the Company for approval his procedure for radiographing the fuel elements. The submitted procedure shall include sample radiographs made by the Seller's procedure.
- C. Any evidence that the fuel element does not meet the requirements of this specification or any specification referenced by it shall reject the fuel element. There shall be no evidence of particles broken from the pellets.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

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Date: Sept. 17, 1964
Rev. No: 1
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

XIV. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XV. RECORDS:

- A. The Seller shall be responsible for maintaining a complete record of all materials and process treatments which are required in the fabrication of the completed fuel element. Four sets of the following information are to be included for each fuel element:
1. Serial number.
 2. Heat number and lot number of material from which the tube was made.
 3. Heat number and lot number of material from which the top and bottom end caps and plunger were made.
 4. Welding current, voltage trace and travel speed for each weld.
 5. Pressure when final closure weld was made.
 6. Heat number and lot number of material from which the spring was made.
 7. Heat number of material used for spacer.
 8. Spacer welding lot number.
 9. Total weight and length of UO_2 stack.
 10. Total weight and length of BeO stack.
 11. Total length of the stack of ceramic pellets.
 12. Blending batch number of uranium dioxide powder used in pellets.
 13. Sintering furnace lot number of uranium dioxide pellets.
 14. Lot number of each ceramic pellet used.
 15. Signature and job title of person who recorded data.
 16. Radiographs of _____ end closure welds, and completed fuel element. (Only one copy required.)
 17. Inspection records on the fuel element (penetrant, leak check visual, radiographic, and dimensional).

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NUCLEAR REACTOR SPECIFICATION
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Date: Sept. 17, 1964
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

XV. RECORDS: (Cont'd)

18. Photographs of sections taken for weld penetrations.
19. Photographs taken of the spacer attachment sections.

A complete report of all such data on each fuel element shall be furnished in five copies to the Company prior to shipment of the completed elements. Additionally, the Seller shall submit to the Company five copies of certified chemical analyses, physical properties data, and such other test reports as are required in the individual component specifications immediately upon receipt of these or upon completion of fabrication in his shop.

The maintenance and submission of these records along with a certificate of compliance that the fuel elements conform to the requirements of this specification shall be a condition of acceptance of the elements.

- B. The Seller shall submit to the Company for information any internal procedures used in the manufacture of the elements or any specification written for a subvendor, provided the information is not considered proprietary.

XVI. RECORD SAMPLES REQUIRED:

The following record samples shall be retained by the Seller and shipped to the Company at the end of the contract:

1. Ten tubes from each lot.
2. Ten end caps and plunger from each heat.
3. Ten springs from each heat.
4. Ten spacers from each heat.
5. Ten BeO pellets from each blending batch.
6. Ten $Gd_2O_3 - Al_2O_3$ pellets from each blend lot.
7. Ten MgO pellets from each lot.
8. Fifteen fuel pellets from each blending batch.
9. Scrap tube after sectioning of 3% of the welds.
10. Metallographic samples on 3% of the brazed spacers.

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A Division of Union Carbide Corporation
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Subject: SPECIFICATION FOR FUEL ELEMENT FOR NUCLEAR REACTOR SERVICE

XVII. SHIPMENT:

The Seller shall be responsible for shipment including obtaining necessary approval for shipment.

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OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-2
Date: July 30, 1964
Rev. No:
Page: 1 of 6

Subject: SPECIFICATION FOR TUBING

I. SCOPE:

This specification defines seamless, cold-drawn type 316 H stainless steel tubing with an inside diameter of 0.460 in. and a wall thickness of 0.020 in. All requirements of ASTM Designation: A 213 - 63 T shall apply except as specifically modified in this specification. If at all possible, this tubing should be made from one heat of material and be manufactured so that the actual dimensional variation of the tubing will be less than this specification allows.

II. MANUFACTURING REQUIREMENTS:

Tubes shall be manufactured in conformance with Dwg. B-108-79 and with this specification.

Tubes shall be extruded or pierced, hot-rolled and cold-drawn, or reduced to size.

III. REFERENCES:

Dwg. B-108-79, "Tube".

ASTM Designation: A 213 - 63 T, "Specification for Seamless Ferritic and Austenitic Alloy - Steel Boiler, Superheater, and Heat Exchanger Tubes (Tentative)"

MET-NDT-4 Rev. 3, "Tentative Methods for Liquid Penetrant Inspection"

AISI, September 1957, "Steel Tubular Products"

ASTM Designation: E 112 - 63, "Standard Method for Estimating the Average Grain Size of Metals"

IV. CHEMICAL COMPOSITION:

The chemical composition of the austenitic steel used shall conform to the requirements of ASTM Designation: A 213 - 63 T, grade TP 316 H. The steel shall also conform to the following requirements:

Cobalt	0.2 wt % (max)
Boron	10 ppm (max)

If redraw material is not available with the proper Boron and/or Cobalt content, these requirements could be relaxed.

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Spec: NRS-2
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBING

V. PHYSICAL PROPERTIES:

The tubing shall be furnished in the annealed condition and free of intergranular attack. This tubing shall be subjected to a high temperature brazing operation and it is necessary that cold work be minimized in order that the grain size of the finished product can be kept to a minimum. The tubing shall also conform to the hydrostatic test requirements specified in ASTM Designation: A 213 - 63 T. The grain size shall be No. 5 or finer as defined in ASTM E 112 - 63.

VI. DIMENSIONS AND TOLERANCES:

- A. The inside diameter shall be 0.460 in. $\pm$ 0.001. "Inside Diameter" here does not mean "average inside diameter", but refers to actual diameter at any given plan normal to the axial center line.
- B. The wall thickness shall be 0.020 in. $\pm$ 0.002. "Wall Thickness" does not mean "average wall thickness", but refers to wall thickness in any plane normal to the axial center line. All dimensional tolerance measurements shall be made after the hydrostatic test is performed.
- C. The tubing shall be furnished in accordance with Dwg. B-108-79.
- D. Corners formed by ends of tubing and longitudinal surfaces shall be square and deburred with a maximum chamfer of 0.005 in.
- E. The tubing shall be straight within 0.030 in. per 3-ft length as stated in AISI, September 1957, "Steel Tubular Products".

VII. SURFACE FINISH AND CONDITION:

The tubing shall have a bright surface finish on the inside surfaces and shall be free of scale and oxide film or other foreign materials as determined by visual inspection. The outside surface shall be polished using a belt of 320 grit or finer. Tubing shall be furnished free of seams, cracks, laps, and intergranular attack. All inclusions, pits, gouge marks, and score marks in excess of 10% of the wall thickness shall be cause for rejection. (A discoloration over a narrow band extending the length of the tube on the inside surface was evaluated and accepted.) I

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OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-2
Date: August 12, 1965
Rev. No: 1
Page: 3 of 6

Subject: SPECIFICATION FOR TUBING

VIII. ACCEPTANCE TESTS:

A. Nondestructive

1. Liquid Penetrant. - A 100% liquid-penetrant inspection shall be performed by the Seller on the entire outside diameter surface of the finished tubes in accordance with MET-NDT-4 Rev. 3, "Tentative Methods for Liquid Penetrant Inspection".

2. Ultrasonic. - Ultrasonic inspection shall be performed on all tubes.

- a. Technical requirements: The tubing shall be inspected at the completion of the manufacturing process. No drawing operation shall be accomplished after the ultrasonic inspection.
- b. Inspection equipment: The instruments and accessory equipment shall be of the pulse-reflection type with sufficient sensitivity to distinguish the reference notches as required during calibration.

The transducer employed shall have no dimension greater than 1-in.

- c. Calibration standards: A calibration standard shall be prepared from tubing taken from the same heat and manufactured by the same processes as the tubing to be inspected and shall be free of defects; the tubing used for the calibration standard shall be the same size as the tubing to be inspected and shall be in the as-polished condition. A longitudinal reference notch, 1/4-in. long and with a maximum depth of 0.0025 in., (the depth shall include the highest point of the metal due to upset, although "deburring" is permitted) shall be machined on the outside and inside surfaces of the standard. The notch may be made by the electric-arc-discharge method. If both reference notches are on the same end of the standard, they shall be at least 120° apart. The included angle of the reference notch shall not exceed 60°. (Note: The standard used had in the outer surface a notch 0.0048 in. wide × 0.0018 to 0.0019 in. deep with a 96° included angle and in the inner surface a notch 0.0046 in. wide × 0.0018 in. deep with a 104° included angle.)
- d. Equipment calibration: Using the calibration standard specified in Section VIII-A-2-c, the equipment shall be adjusted to product indications as nearly as possible the same height from both the inside and outside reference

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBING

VIII. ACCEPTANCE TESTS: (Cont'd)

notches. The rejection alarm shall be adjusted to signal at the indication of the lesser amplitude.

The equipment shall be calibrated at the same circumferential speed and rate of translation (feed helix) which will be used for the inspection of the tube.

The relative translation (feed helix) of the crystal with respect to the tube shall be the lesser of $3/8$ in./revolution or one half the crystal or collimator width or diameter.

- e. Inspection procedure: The material shall be tested for radial defects in both circumferential directions under conditions which are used for calibration of the equipment.

The equipment shall be recalibrated as specified in Section VIII-A-2-d after the inspection of ten lengths of tubing or when any adjustment to the equipment is made.

When significant adjustment of the equipment is required during the calibration check (any time the inside and outside reference notches do not present a rejectable signal), the preceding ten tubes shall be completely reinspected.

- f. Defects and rejection: All indications of discontinuities equal to or greater than the lesser indication of the reference notches as described in Section VIII-A-21-d shall be considered as defects and shall be rejected. If the defect is reworkable, it may be removed and reinspected ultrasonically. Reworked material shall conform to the dimensional requirements of this specification.

3. Hydrostatic Test. - Each tube shall be tested at a hydrostatic pressure of 800 psi prior to dimensional inspection.

4. Dimensional Inspection. -

- a. Mechanical measurements of the wall thickness shall be made at 90° intervals or less on each end of each tube (cut to length) to determine compliance with Section VI-B of this specification.

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBING

VIII. ACCEPTANCE TESTS: (Cont'd)

- b. Each finished tube shall be subjected to an air-gage inspection of the inside diameter along the entire length to determine compliance with Section VI-A of this specification. Diametrical measurements shall be made at intervals of approximately 90 deg.
- c. A random 20% sample of the tubes in finished condition and cut to length shall be subjected to an ultrasonic-resonance inspection for wall-thickness determination. The accuracy of the test equipment for use in this measurement shall be established by taking readings at a point near the end of one or more tubes and checking by measurement with a micrometer.

A continuous helical span shall be accomplished on the inspected tubing with a pitch not to exceed 1 in. An acceptable alternate will be circumferential scans on 1-in. centers. If one or more tubes of the 20% sampling are determined not to meet the dimensional requirements as stated in this specification, an additional 20% sampling shall be examined in the same manner. A rejection rate of 10% or more of the tubes shall be cause for 100% inspection of the entire lot.

Tubes not subjected to ultrasonic resonance tests for wall thickness by the Seller are subject to such tests by the Company. The tubes are subject to rejection if the tests by the Company show that the wall thickness does not conform to the dimensional requirements of this specification.

- d. The Seller shall perform inspection on each tube for length, end squareness, and straightness to determine compliance with Sections VI-C, VI-D, and VI-E, respectively, of this specification.
5. Visual. - Each tube shall be visually inspected under direct daylight fluorescent lighting of at least 100 footcandles to ensure conformance to Section VII of this specification.

B. Destructive

- 1. Metallographic examination at 100X of one section of tubing selected at random from each lot shall be prepared to determine compliance with Section V of this specification.

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBING

VIII. ACCEPTANCE TESTS: (Cont'd)

2. Metallographic specimens shall be forwarded by the Seller to the Company at time of shipment.

IX. MARKING AND PACKING:

- A. Each tube shall be marked by means of a sulfur-free ink with the following:
 1. NRS-2
 2. Manufacturer's private identification mark
 3. Lot number*
 4. Heat number*

*May be omitted if all the tubing is from the same lot and heat.

- B. Each tube shall be packed in such a manner as to prevent damage and to maintain the cleanliness of the tubing during handling and shipment.

X. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XI. TEST REPORTS:

Four certified copies of test reports shall be furnished by the Seller to the Company at the time of shipment of each lot of material. At the time of shipment, the Seller shall also furnish to the Company four copies of a Manufacturer's certification of compliance to this specification and to ASTM A 213 - 63 T.

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NUCLEAR REACTOR SPECIFICATION
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OAK RIDGE NATIONAL LABORATORY

Spec: NRS-3
Date: September 17, 1964
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

I. SCOPE:

This specification defines fully enriched fuel pellets made of uranium dioxide, 0.456 OD, approximately 1/2-in. long for high temperature nuclear service.

II. MATERIALS:

The Company shall supply to the Seller the uranium hexafluoride to complete the full core loading plus a 25% surplus. R

The Seller shall pay for all uranium metal losses. R

The Seller shall pay the cost of reprocessing all scrap material to UF₆. This cost shall also include the cost of transportation. R

The uranium hexafluoride will be enriched to the specified $93.15 \pm .15\%$ by weight in ²³⁵U. The Seller's conversion and fabrication processes shall be such that the isotopic composition of the finished uranium dioxide fuel pellets shall not differ from that of the uranium hexafluoride by more than 0.1% of the contained amount. Example: If the UF₆ is enriched to 93.1%, then the isotopic analysis may vary from 93.0 to 93.2.

III. REFERENCES:

Dwg. A-108-82, "UO₂ Pellet".

TID-7015, Section I, "ORNL Master Analytical Manual"*

Analytical Chemistry, 32, 610 (1960), "Determination of O/U Ratio in UO₂", H. Kubota

IV. MANUFACTURING REQUIREMENTS:

The uranium dioxide pellets shall be manufactured from virgin powder in accordance with Dwg. A-108-82, "UO₂ Pellet", and with this specification. No oxidized or reduced U scrap shall be used. R

*This document is available from the Offices of Technical Services, Department of Commerce, Washington 25, D. C.

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NUCLEAR REACTOR SPECIFICATION
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

V. CHEMICAL COMPOSITION:

The finished fuel pellets shall conform to the following chemical analysis:

Total Uranium	Not less than 88.0 wt %
Carbon	500 ppm (max)
Nitrogen	500 ppm (max)
Iron	500 ppm (max)
Calcium, Silicon & Aluminum	Sum shall not exceed 300 ppm

The oxygen-to-uranium ratio of the finished fuel pellets shall be within the range 2.00 to 2.01.

VI. DENSITY:

The bulk density of the fuel pellet shall be 94-97% of theoretical density for uranium dioxide bodies. Consider theoretical density to be 10.96 g/cm³.

VII. DIMENSIONAL:

The fuel pellet shall conform to the dimensional tolerances given on Dwg. A-108-82.

VIII. DRYNESS:

The finished pellets shall be sufficiently dry so that, when heated for four hours under vacuum at 250°C, the weight loss shall not exceed 10 ppm. The pressure inside the oven shall not exceed 1 mm Hg.

IX. SURFACE FINISH AND CONDITION:

A. Chipping

Chipping on the outside cylindrical surface shall not exceed 10% of the outside cylindrical surface area. Chipping on each end of the pellet shall not exceed 25% of the surface area of one end of the pellet. No chip shall be greater than 1/4 in. in lateral dimension nor greater than 1/16 in. in depth. The vendor shall submit a visual standard for chipped pellets for the Company's approval. Pellets that are defective based on this visual standard shall be scrapped. (Notice: No visual standard was selected at the request of Westing- I house.)

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

IX. SURFACE FINISH AND CONDITION: (Continued)

B. Cracks

Radial cracks exceeding 25% of the diameter shall be cause for rejection. Radial cracks are defined as cracks observed at the end or ends of the pellet which are in a radial direction.

Circumferential cracks shall be cause for rejection if the crack is continuous over an arc of 45 deg or more. A circumferential crack is defined as a crack observed at the end of the pellet or on the circumferential surface and running parallel to the circumference or perpendicular to a radial direction. A circumferential crack of 180 deg shall be allowed provided no more than one crack per pellet exists and that this crack is located in the center one third of the pellet.

C. Sponginess or Microcracking.

Excessive sponginess or microcracking, as illustrated in Fig. 1, shall be cause for rejection.

D. Surface Area

The BET surface area shall not exceed $25 \text{ cm}^2/\text{g}$ as determined in accordance with NRS-10.

X. ACCEPTANCE TESTS:

A. Nondestructive

1. Visual. - The fuel pellets shall be subjected to 100% visual inspection to assure conformance with Section IX of this specification. The inspection shall be performed under direct daylight fluorescent illumination of at least 100 footcandles.
2. Dimensional. - One percent of each day's production of pellets, randomly selected, shall be dimensionally inspected to assure conformance to Section VII of this specification. If any of these pellets do not meet dimensional tolerances, the entire day's production shall be 100% dimensionally inspected.
3. Density. - One pellet from each boat of pellets, selected

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

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Fig. 1. Photograph of UO_2 Fuel Pellets Illustrating Excessive Sponginess and Microcracking. The pellet on the left is acceptable. The pellet on the right in the photograph is unacceptable. The pellet in the center is borderline, but is also unacceptable.

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

X. ACCEPTANCE TESTS: (Continued)

randomly, shall be measured and weighed to determine bulk density. If any of these pellets do not meet the density as specified in Section VI of this specification, every pellet from that boat load* shall be subjected to density determination and shall be accepted or rejected accordingly.

4. Dryness. - One percent of the finished pellets shall be selected randomly for dryness tests prior to packaging. The dryness test shall consist of heating the pellets to 250°C for four hours under vacuum. The pressure inside the oven shall not exceed 1 mm Hg. The pellets shall be weighed in groups before and after heating. The weighings shall be performed with the pellets at room temperature. The size of each group shall not be less than 10 nor more than 100 pellets.

If the weight loss for each group of pellets from one dryness testing oven lot does not exceed 10 ppm, all pellets represented by that dryness testing oven lot shall be accepted. If the weight loss of any of the weighing groups in a dryness testing oven lot is greater than 10 ppm, the pellets represented by that dryness testing oven lot shall be rejected unless the Seller is able to demonstrate a 95-95% confidence level that the pellets meet the dryness requirements in Section VIII of this specification. The Seller shall demonstrate this confidence level by conducting sufficient additional dryness tests.

5. BET. - The finished pellets shall be inspected in accordance **N** with NRS-10.

B. Destructive

1. Oxygen-to-Uranium Ratio, Total Uranium, Carbon, and Nitrogen.

- a. Sampling: Two pellets shall be selected randomly from each of the first 10 boat loads for determination for oxygen-to-uranium ratio, total uranium, carbon, and nitrogen. At least one analysis shall be performed on each of the two pellets.

* A boat load is that quantity of pellets in the sintering zone of the furnace at one time.

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

X. ACCEPTANCE TESTS: (Continued)

If the above sampling shows that the pellets meet the specification, the sampling shall be reduced so that three pellets shall be taken from each blending batch.* One pellet each shall be taken from the beginning, middle, and end of each blending batch. Duplicate samples from each of these pellets shall be sent to the Company for testing. If any of the three pellets from each blending batch fail to meet the specification, sampling shall revert to the original cycle (i.e., 10 consecutive furnace lots shall be sampled).

- b. Method of Analysis: The oxygen-to-uranium ratio shall be determined by the polarographic method referenced in Section III of this specification or by an approved alternate method.

Total uranium shall be determined by the potentiometric or volumetric methods according to procedures recommended by the Company** or by an approved alternate method.

- c. Qualification of Seller's Analytical Procedure: Standard samples will be furnished to the Seller by the Company for qualification of the Seller's analytical procedure. This qualification shall be prerequisite to production pressing of the pellets.

*A blending batch is defined as that quantity of uranium dioxide powder that is blended together so that the chemical and isotopic compositions may be assumed to be nearly identical.

**Three suitable methods for the determination of the uranium content of uranium dioxide are found in the ORNL Master Analytical Manual, published as TID-7015, Section I. The methods are:

No. 900719270, Uranium, Volumetric Zinc Amalgram-Potassium Dichromate Method

No. 900719222, Uranium, Potentiometric Ferric Sulfate Method

No. 900719224, Uranium, Automatic Potentiometric Ferric Sulfate Method

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Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

X. ACCEPTANCE TESTS: (Continued)

- d. Acceptance or rejection: If the oxygen-to-uranium ratio and total uranium content do not meet the requirements specified in Section V of this specification, the entire blending batch of sintered pellets shall be rejected unless the Seller performs additional analyses sufficient to assure a 95-95% confidence level that the pellets are within the limits specified.

2. Isotopic and Impurity Analysis

- a. Sampling: One finished pellet representing each blending batch of uranium dioxide powder shall be selected randomly for isotopic analysis.

The Seller shall perform impurity analyses on one finished pellet selected randomly from each blending batch of uranium dioxide powder.

An alternate sampling plan may be used in which 5% of the product will be selected for destructive testing. The product to be tested shall be selected so that an equal number of test specimens is selected from each blending batch.

- b. Acceptance or Rejection: If the isotopic and impurity analyses do not conform to the limits specified in Sections II and V, respectively, of this specification, all the pellets fabricated from that entire batch of powder shall be rejected unless the Seller performs additional analyses sufficient to assure a 95-95% confidence level that the pellets are within the limits specified.

XI. INSPECTION:

The Seller shall notify the Company five (5) days in advance of date set for production testing in order that the Company's inspector may be present to witness testing.

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A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

XII. TEST REPORTS:

Four certified copies of dryness test reports shall be furnished to the Company prior to shipment of the pellets. Four copies of certified chemical analyses for oxygen-to-uranium ratio and total uranium, and density determinations shall be furnished for each furnace lot of sintered pellets. The analyses and density determinations shall be performed as described in Section X-B-1 of this specification.

Four copies of ²³⁵U certified chemical analyses for impurities and isotopic analysis for ²³⁵U content shall be furnished to the Company prior to shipment for one pellet from each blended batch of uranium dioxide powder.

The Seller shall be responsible for maintaining a complete record of all materials and process treatments which were used to fabricate these pellets. This information is to include such as the following:

1. Virgin powder surface area
2. Type and amount of binder and lubricant
3. Presinter temperature, gas, time, cooling and heating rate
4. Press pressure
5. Sinter temperature, gas, time, cooling and heating rate
6. Grinding lubricant
7. Omitted

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Four copies of these material and process treatments used for each batch of material will be sent to the Company upon completion of the order, provided such information is not considered proprietary.

The Seller will supply four copies of a certification of compliance that all the requirements of NRS-3 have been met.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-3
Date: Sept. 17, 1964
Rev. No: 1
Page: 9 of 9

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

XIII. SAMPLE PELLETS:

Two finished pellets representing each blending batch of material shall be furnished to the Company for evaluation purposes. (These are in addition to those required in NRS-1, Section XI.)

XIV. PACKING AND SHIPPING:

The Seller will be responsible for shipment of the pellets. The Seller will get all necessary approval for shipment. All pellets in each shipment must be identified according to blending batch.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-4
Date: July 30, 1964
Rev. No: 0
Page: 1 of 2

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR MAGNESIUM OXIDE PELLETS

I. SCOPE:

This specification defines magnesium oxide pellets for high temperature nuclear service.

II. MANUFACTURING REQUIREMENTS:

The magnesium oxide pellets shall be manufactured in accordance with Dwg. A-108-83 and with this specification.

III. REFERENCES:

Dwg. A-108-83, "MgO Pellet."

IV. CHEMICAL COMPOSITION:

The material shall conform to the following analysis:

SiO ₂ -- 0.2 wt % (max)	Fe -- 0.1 wt % (max)
Al ₂ O ₃ -- 0.35 wt % (max)	CaO -- 0.2 wt % (max)
B -- 20 ppm (max)	MgO -- Remainder

V. DENSITY:

The pellets shall be sintered to a density of $2.6 \text{ g/cm}^3 \pm 0.6$.

VI. DIMENSIONAL TOLERANCES:

The magnesium oxide pellets shall conform to the dimensions and tolerances specified on Dwg. A-108-83.

VII. CLEANLINESS:

The pellets shall be clean and free of moisture, dirt, grease, oil, or fabrication lubricants.

VIII. SURFACE CONDITION:

The surfaces shall be free of cracking or chipping as determined by visual inspection.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-4
Date: July 30, 1964
Rev. No: 0
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR MAGNESIUM OXIDE PELLETS

IX. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

X. TEST REPORTS:

The Seller shall furnish to the Company four copies of certified chemical analyses of finished pellets. At the time of shipment, the Seller shall also furnish to the Company four copies of a certification stating that all requirements of this specification have been met.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-5
Date: July 30, 1964
Rev. No: 0
Page: 1 of 2

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR BERYLLIUM OXIDE PELLETS

I. SCOPE:

This specification defines beryllium oxide pellets for high temperature nuclear service.

II. MANUFACTURING REQUIREMENTS:

The beryllium oxide pellets shall be manufactured in accordance with Dwg. A-108-84 and with this specification.

III. REFERENCES:

Dwg. A-108-84, "BeO Pellet."

IV. CHEMICAL COMPOSITION:

The material shall conform to the following analysis:

SiO ₂	-- 0.2 wt % (max)	Fe	-- 0.1 wt % (max)
Al ₂ O ₃	-- 0.35 wt % (max)	CaO	-- 0.2 wt % (max)
B	-- 20 ppm (max)	BeO	-- Remainder

V. DENSITY:

The pellets shall be sintered to a density of 2.8 to 2.9 g/cm³.
(Note: Actual pellets were accepted with density range 2.91 to 2.93 g/cm³).

VI. DIMENSIONAL TOLERANCES:

The beryllium oxide pellets shall conform to the dimensions and tolerances specified on Dwg. A-108-84.

VII. CLEANLINESS:

The pellets shall be clean and free of moisture, dirt, grease, oil, or fabrication lubricants.

VIII. SURFACE FINISH AND CONDITION:

Chipping on the surfaces shall not exceed 5% of the surface area. Chipping on the surface of each end of the pellets shall not exceed 5% of the surface area of one end of the pellets. No chipped area shall be greater than 1/16 in. in largest lateral dimension nor greater than 1/32 in. deep. The finished material shall be free of cracks.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-5
Date: July 30, 1964
Rev. No: 0
Page: 2 of 2

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR BERYLLIUM OXIDE PELLETS

IX. TEST REQUIREMENTS:

A. Non-Destructive

1. Visual. - All pellets shall be subjected to visual inspection under direct daylight fluorescent lighting of at least 100 footcandles to insure conformance with this specification.
2. Dimensional. - All individual pellets shall be subjected to dimensional inspection to determine conformance with requirements set forth in Dwg. A-108-84.
3. Weight. - All pellets shall be weighed to determine conformance with requirements set forth under Section V, "Density."

B. Destructive

1. A sample of each lot of beryllium oxide powder shall be analyzed to determine conformance with purity set forth under "Chemical Composition."
2. Two sintered pellets from each blending batch shall be broken into quarters and two opposite quarters analyzed separately to determine conformance with Section IV under "Chemical Composition." The remaining quarters shall be forwarded to the Company for analysis.
3. If the total beryllium content does not meet the requirements of Section IV under "Chemical Composition," retests shall be made on four additional pellets per lot, each of which shall conform to the requirements specified.

X. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XI. TEST REPORTS:

The Seller shall furnish to the Company four copies of certified chemical analyses of finished pellets. At the time of shipment, the Manufacturer shall also furnish to the Company four copies of a certification stating that all requirements of this specification have been met.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-6
Date: July 30, 1964
Rev. No: 0
Page: 1 of 4

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR GADOLINIUM OXIDE - ALUMINUM OXIDE PELLETS

I. SCOPE:

This specification covers gadolinium oxide - aluminum oxide (Gd_2O_3 - Al_2O_3) pellets for use in high temperature nuclear reactors.

II. REFERENCES:

Dwg. A-108-85, " Gd_2O_3 - Al_2O_3 Pellet."

III. MANUFACTURE:

Individual gadolinium oxide - aluminum oxide (Gd_2O_3 - Al_2O_3) pellets shall be manufactured in accordance with this specification, and Dwg. A-108-85.

IV. DEFINITIONS:

1. A lot of gadolinium oxide powder consists of all Gd_2O_3 powder identified by the same lot number.
2. A lot of aluminum oxide powder consists of all Al_2O_3 powder of the same grade designation received at the same time.
3. A blend lot consists of all Al_2O_3 - Gd_2O_3 powder and up to 15% recycled sintered or green scrap which are mixed together at the same time.
4. A pressing lot consists of all shapes pressed from a blend lot to the same green density range.
5. A sintering lot consists of all shapes pushed through the sintering furnace at the same time.

V. CHEMICAL COMPOSITION:

1. Starting aluminum oxide powder shall be of 99.9% minimum purity based on ignited weight and aluminum oxide content.
2. Starting gadolinium oxide powder shall be of 99.9% purity based on ignited weight and rare earth content.
3. Finished shapes ready for canning shall consist primarily of Al_2O_3 and Gd_2O_3 or compounds thereof and shall have a composition of 70^{+2}_{-0} wt % Gd_2O_3 .

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-6
Date: July 30, 1964
Rev. No: 0
Page: 2 of 4

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR GADOLINIUM OXIDE - ALUMINUM OXIDE PELLETS

VI. DENSITY:

1. For purpose of density calculations, the following parameters shall be used:

Theoretical density of Al_2O_3 - 3.96 g/cm³

Theoretical density of Gd_2O_3 - 7.407 g/cm³

Theoretical density 30% Al_2O_3 - 70% Gd_2O_3 - 5.873 g/cm³

Theoretical density 29% Al_2O_3 - 71% Gd_2O_3 - 5.914 g/cm³

Theoretical density 28% Al_2O_3 - 72% Gd_2O_3 - 5.955 g/cm³

2. The sintered pellets shall have a minimum density of 95% of theoretical.

VII. DIMENSIONS:

Individual pellets shall be as shown in Dwg. A-108-85.

VIII. SURFACE FINISH AND CONDITION:

Chipping on the surfaces shall not exceed 5% of the surface areas. Chipping on the surface of each end of the pellets shall not exceed 5% of the surface area of one end of the pellets. No chipped area shall be greater than 1/16 inch in largest lateral dimension nor greater than 1/32 inch deep. The finished material shall be free of cracks.

IX. TEST REQUIREMENTS:

A. Non-Destructive

1. Visual. - All pellets shall be subjected to visual inspection under direct daylight fluorescent lighting of at least 100 footcandles to insure conformance with this specification.
2. Dimensional. - All individual pellets shall be subjected to dimensional inspection to determine conformance with Dwg. A-108-85.
3. Weight. - All pellets shall be weighed to determine conformance with requirements set forth under Section VI, "Density".

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-6
Date: July 30, 1964
Rev. No: 0
Page: 3 of 4

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR GADOLINIUM OXIDE - ALUMINUM OXIDE PELLETS

IX. TEST REQUIREMENTS: (Continued)

B. Destructive

1. A sample of each lot of aluminum oxide powder shall be analyzed to determine conformance with purity set forth under "Chemical Composition."
2. A sample of each lot of gadolinium oxide powder shall be analyzed to determine conformance with purity set forth under "Chemical Composition."
3. Two sintered pellets from each blend lot and from different sintering lots shall be broken into quarters and two opposite quarters analyzed separately to determine conformance with Section V, Par. 3, under "Chemical Composition." The remaining quarters shall be forwarded to the Company for check analysis.
4. If the total gadolinium content does not meet the requirements of Section V, Par. 3, under "Chemical Composition," retests shall be made on four additional pellets per blend lot, each of which shall conform to the requirements specified.

X. THERMAL CYCLE TEST:

A thermal cycle test shall be performed by the Seller on each pellet from a temperature of $1475 \pm 25^{\circ}\text{F}$ to room temperature in 10 seconds. The method of thermal cycling shall be approved by the Company prior to use.

XI. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XII. TEST REPORTS:

The Seller shall furnish to the Company four copies of the following:

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-6
Date: July 30, 1964
Rev. No: 0
Page: 4 of 4

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR GADOLINIUM OXIDE - ALUMINUM OXIDE PELLETS

XII. TEST REPORTS: (Continued)

- a. Chemical analyses on starting virgin aluminum oxide powder and starting virgin gadolinium oxide powder.
- b. Chemical analyses on sintered pellets.
- c. Visual inspection of sintered pellets.

In addition the Manufacturer shall supply a certification of compliance that all requirements of this specification have been met.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-7
Date: August 12, 1965
Rev. No: 1
Page: 1 of 3

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR END CAPS AND PLUNGER

I. SCOPE:

This specification defines type 316 H stainless steel end caps and plunger for high temperature nuclear service.

II. MANUFACTURING REQUIREMENTS:

The upper and lower end caps and plunger shall be manufactured in conformance with Dwgs. A-108-76, A-108-75, A-108-77, and with this specification.

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III. REFERENCES:

Dwg. A-108-76, "End Cap, Upper"
Dwg. A-108-75, "End Cap, Lower"
Dwg. A-108-77, "Plunger"

ASTM Designation: A 276 - 63 T, "Specification for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (Tentative)."

MET-NDT-4 Revision 3, "Tentative Methods for Liquid Penetrant Inspection."

IV. CHEMICAL COMPOSITION:

The chemical composition of the steel used shall conform to ASTM Designation: A 276 - 63 T, type 316. The steel shall also conform to the following chemical content requirements on a weight basis:

Carbon - - - 0.04 - 0.10

Cobalt - - - 0.2% (max)

Boron - - - 10 ppm (max)

The minimum solution heat treating temperature shall be 2000°F.

V. PHYSICAL AND MECHANICAL PROPERTIES:

The physical and mechanical properties shall conform to the requirements of the latest revision of ASTM Designation: A 276 - 63 T, type 316 stainless steel.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-7
Date: August 12, 1965
Rev. No: 1
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR END CAPS AND PLUNGER

VI. DIMENSIONAL TOLERANCES:

The upper and lower end caps and plunger shall conform to the dimensions and tolerances specified on Dwgs. A-108-76, A-108-75, and A-108-77, respectively.

VII. SURFACE FINISH AND CONDITION:

Surfaces of the upper and lower end caps and plunger shall conform to the finishes specified on Dwgs. A-108-76, A-108-75, and A-108-77, respectively.

All surfaces shall be free of cracks, pits, laps, seams, gouges, and intergranular attack.

Surfaces shall be free of scale, oxide film, dirt, oil, grease, or other foreign material.

VIII. ACCEPTANCE TESTS:

A. Nondestructive

1. Visual. - One hundred percent visual inspection shall be performed under direct daylight fluorescent lighting of at least 100 footcandles to ensure conformance with the requirements of Section VII of this specification.
2. Dimensional. - One hundred percent dimensional inspection shall be performed to ensure conformance to the requirements of Section VI of this specification. Two diametral measurements, 90 deg apart, shall be made of the end cap and plunger diameters and on the diameter of the projection on the bottom end cap.
3. Liquid Penetrant. - One hundred percent liquid-penetrant inspection for discontinuities shall be performed over the entire surface of the finished plunger and end caps in accordance with MET-NDT-4, Revision 3, "Tentative Methods for Liquid Penetrant Inspection," except that minimum penetrant soak time shall be 30 minutes. A 5-min maximum emulsification shall also be allowed on the upper end cap.

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B. Destructive

The bar stock or forgings from which the end caps and plunger are fabricated shall be sampled in accordance with ASTM Designation: A 276 - 63 T for use in chemical analysis and physical tests to assure conformance of the finished pieces with Sections IV, V, and VII of this specification.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-7
Date: August 12, 1965
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR END CAPS AND PLUNGER

VIII. ACCEPTANCE TESTS (Continued)

Metallographic sections shall be prepared for examination, measured, and photographed as specified in ASTM Designations: E 2 - 49 T and E 3 - 58 T to insure compliance with Section VII of this specification. The photographs shall become the property of the Company and shall be delivered with or prior to final shipment.

IX. INSPECTION:

The Seller shall notify the Company five (5) days in advance of date set for starting of production testing in order that the Company's inspector may be present to witness testing.

X. TEST REPORTS:

Four certified copies of test reports shall be furnished by the Seller to the Company at the time of shipment. At the time of shipment, the Seller shall also furnish to the Company four copies of a certification stating that all requirements of this specification have been met.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-8
Date: July 30, 1964
Rev. No: 0
Page: 1 of 3

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR SPRINGS

I. SCOPE:

This specification defines TZM molybdenum springs for high temperature nuclear service.

II. REFERENCES:

- A. Dwg. A-108-78, "Spring"
- B. MET-NDT-4, Revision 3, "Tentative Methods for Liquid Penetrant Inspection"

III. CHEMICAL COMPOSITION:

- A. The chemical composition of the billets from which the wire is produced shall conform to the following limits:

<u>Element</u>	<u>Maximum %</u>	<u>Minimum %</u>
Carbon -----	0.04	0.01
Titanium -----	0.55	0.40
Zirconium -----	0.12	0.06
Gaseous elements (listed below) -----	0.005	-
Trace elements (listed below) -----	0.020	-
Molybdenum (by difference) -----	-	99.25
Oxygen -----	0.0025	-
Hydrogen -----	0.0005	-
Nitrogen -----	0.002	-
Iron -----	0.010	-
Nickel -----	0.002	-
Silicon -----	0.008	-

IV. CHECK ANALYSIS:

A check analysis shall be performed on a spring from each heat of material and shall conform to the requirements of Section III, "Chemical Composition".

(Note: The check analysis ran as high as 59 ppm on oxygen and 25 ppm I on nitrogen.)

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-8
Date: July 30, 1964
Rev. No: 0
Page: 2 of 3

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR SPRINGS

V. STRUCTURAL CONDITION:

Springs shall be supplied in a stress-relieved condition. The stress relieving treatment, for the purpose of reducing macro-stresses, consists of a heat treatment at a temperature that can be tolerated without a significant drop from the as-worked hardness.

VI. MECHANICAL PROPERTIES:

- A. A spring from each heat of starting wire shall be checked for hardness. The hardness shall be 260 - 320 DPH (10 Kg) or its equivalent.
- B. A tensile test shall be performed on sample wire from each heat of the material from which the wire was made and shall have the following minimum properties:

<u>Tensile Strength</u>	<u>Yield Strength</u>	<u>Elongation in 1-in.</u>
115,000 psi	0.2% offset	18%
	100,000 psi	

VII. DIMENSIONAL AND TOLERANCES:

The dimensional and tolerance for each spring shall conform to Dwg. A-108-78, "Spring".

VIII. SURFACE FINISH:

The springs shall be free of oxide film or other foreign material. The surface finish of the spring shall be 125 rms or better.

IX. SURFACE INSPECTION:

- A. Each spring shall be penetrant inspected in accordance with MET-NDT-4, Revision 3.
- B. Each spring shall be visually inspected under direct daylight fluorescent lighting of at least 100 footcandles to ensure conformance to Section VII and VIII of this specification.

X. MARKING:

Each spring will be tagged with the following:

- A. NRS-8
B. Manufacturer's private identification number
C. Heat Number

(Note: Heat number identification was lost on some of the springs.) I

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-8
Date: July 30, 1964
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Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR SPRINGS

XI. INSPECTION:

The Seller shall notify the Company five (5) days in advance of date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XII. REPORTS:

Four certified copies of test reports shall be furnished by the Seller to the Company at the time of shipment. The test reports shall include the results of all tests performed on the wire or spring and a manufacturer's certification of compliance to NRS-8.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-9
Date: Aug. 12, 1964
Rev. No: 1
Page: 1 of 5

Subject: SPECIFICATION FOR TUBE SUBASSEMBLIES

I. SCOPE:

This specification defines the attachment of three clusters of six spacers to a tube by brazing for use in high temperature nuclear service.

II. MANUFACTURING REQUIREMENTS:

The spacers shall be attached by brazing with Microbraz 50 in accordance with Dwg. B-108-81 and this specification.

The brazing temperature shall not exceed 1925°F and the time above 1800°F shall not exceed 27 minutes.

The spacers may be machined to meet the dimensional requirements of Dwg. B-108-81. No machining is allowed on the tube.

The spacers may be held in place for brazing by a spot weld provided the procedure is qualified in accordance with Section VI-B.

III. REFERENCES:

Dwg. B-108-81, "Subassembly, Tube"

NRS-2, "Specification for Tubing"

ASTM Designation: E2 - 49 T, "Preparation of Micrographics of Metals and Alloys"

ASTM Designation: E3 - 58 T, "Preparation of Metallographic Specimens"

ASTM Designation: E112 - 63, "Estimating the Average Grain Size of Metals"

IV. MATERIALS:

The tubing shall be in accordance with NRS-2.

The spacer material shall be type 316 stainless steel with certified chemistry and mechanical properties.

V. DIMENSIONAL TOLERANCES:

The tube spacer assembly shall conform to the dimensional tolerances specified on Dwg. B-108-81.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-9
Date: Aug. 12, 1964
Rev. No: 1
Page: 2 of 5

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBE SUBASSEMBLIES

VI. QUALIFICATION:

The Seller must submit to the Company for approval a procedure for brazing and a qualification sample of two tube subassemblies (one sectioned) according to that procedure prior to any production brazing. Thereafter any changes in brazing procedure must be approved by the Company. If a rebraze cycle is to be used, the qualification sample must go through the temperature cycle the maximum number of times planned for any tube subassembly. One qualification sample shall be sectioned and examined in accordance with Section VII-B by the Seller and the photograph and the metallographic samples submitted to the Company with the brazing procedure.

If any spot welding is performed, the Seller must submit prior to any production welding his procedure for spot welding along with two subassemblies (one sectioned) with the spacers spot welded in place using the maximum pressure, voltage and current allowed by the procedure. One of the subassemblies shall be sectioned through the spot welds and examined and photographed in accordance with ASTM Designation E2 - 49 T and E3 - 58 T respectively by the Seller. The photographs and the sections will be submitted to the Company along with the qualification procedure. There shall be no evidence of cracks. The weld penetration into the tube shall not be greater than 5 mils.

VII. ACCEPTANCE TEST:

A. Nondestructive

1. Visual Inspection. - All subassemblies shall be visually examined using a magnification of from 3 to 20X under direct daylight fluorescent illumination of at least 100 foot candles.

The brazed joint shall be a continuous uniformly filled joint extending at least 75% around the circumference of the spacer.

2. Dimensional Inspection. - The following dimensional inspection shall be performed:

- a. An air gage check on the ID of the tubing under each cluster.
- b. A Go-No-Go gage on the OD of each cluster of spacers.
- c. A check to see that one spacer is in line with a spacer in each of the other two clusters.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-9
Date: Aug. 12, 1964
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Subject: SPECIFICATION FOR TUBE SUBASSEMBLIES

VII. ACCEPTANCE TEST: (Continued)

- d. A Go, No-Go check between adjacent spacers in the clusters.
- e. A Go, No-Go check on the height of each spacer above the OD of the tube.
- f. All Go and No-Go gages will become the property of the Government upon completion of the contract.

B. Destructive Examination

1. Metallographic Examination of the Brazed Subassembly. -

- a. Representative specimens (a minimum of 3% of the brazing lot) should be placed in with the brazing batch. These specimens are to be randomly placed in the brazing fixture. Specimens (an equivalent to a 3% sample of the brazing batch) should be selected for testing. The representative specimen tubes are to be approximately 6-in. lengths of Type 316H stainless steel tube of the same tubing used in the subassemblies but with one cluster of spacers. If one or more of the specimens are rejected, then twice the original number should be selected for testing. If one or more of the second group are determined to be rejectable, then the entire lot (defined in section IX-b) will be considered rejectable and the manufacturer will be responsible for initiation of corrective action; sampling will again go into effect as described above. R
- b. The sections shall be prepared for examination and photographed as specified in ASTM Designations: E2 - 49 T and E3 - 58 T. The photographs shall become the property of the Company and shall be delivered with or prior to final shipment.
- c. The grain size shall be measured on all sectioned brazed subassemblies in accordance with ASTM Designation: E112 - 63 and the minimum number of grains across the wall of the tube shall not be less than 5. (A line perpendicular with the axis of the tube shall pass through a minimum of 5 grains.)

2. Metallographic Examination of the Spot Welded Subassembly. -

- a. A sample of 1% of the spot welded subassemblies shall be selected by the Company's inspector for examination. If one or more assemblies of the 1% random sample are rejected, then twice the original number of assemblies shall be

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-9
Date: Aug. 12, 1964
Rev. No: 1
Page: 4 of 5

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBE SUBASSEMBLIES

VII. ACCEPTANCE TEST: (Continued)

selected for testing. If one or more of the second group are determined to be rejectable, then the entire group made by that method will be considered rejectable and the Manufacturer will be responsible for initiation of corrective action. After initiation of corrective action, sampling will again go into effect as described above.

- b. The tube shall be sectioned transversely through the weld area.
- c. The sections shall be prepared for examination, and photographed as specified in ASTM Designations: E2 - 49 T and E3 - 58 T. The photographs shall become the property of the Government and shall be delivered with or prior to final shipment.
- d. There shall be no evidence of cracks. The weld penetration into the tube shall not be greater than 5 mils.

VIII. INSPECTION:

The Seller shall notify the Company five (5) days in advance in order that the Company's inspector may be present to witness all brazing, spot welding and inspection, including qualification test.

IX. RECORDS:

- A. The Seller shall be responsible for maintaining a complete record of all materials and process treatments which are required in the attachment of the spacers. The information to be included shall be such as follows: lot numbers, inspection or test results, dimensional measurements, spot welding or brazing parameters, etc.
- B. On brazed subassemblies, the Seller shall provide a thermal trace for each brazing furnace lot of tubes to determine conformation with Section II of this specification. A lot shall be defined for a batch furnace as the tubes in the furnace at one time. A lot shall be defined for a continuous furnace as the tubing run in a time not to exceed two hours. If a continuous furnace is used, a thermocouple shall be run through the furnace before and after each brazing lot. During the run on a continuous furnace,

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-9
Date: Aug. 12, 1964
Rev. No: 1
Page: 5 of 5

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR TUBE SUBASSEMBLIES

IX. RECORDS: (Continued)

the furnace setting shall not be changed. In the case of a continuous furnace a thermal trace of the control couple and a time-temperature plot of the thermocouple that was run through the furnace before and after each lot shall be required. Each tube subassembly shall be identified by its brazing furnace lot number.

- C. The maintenance and submission of four sets of these records along with a certified statement of compliance that the attachment was performed in accordance with this specification shall be a condition of acceptance of the subassemblies.

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NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec: NRS-10
Date: July 30, 1964
Rev. No: 0
Page: 1 of 1

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: SPECIFICATION FOR BET SURFACE AREA

I. SCOPE:

This specification defines BET surface area requirements for UO_2 pellets made in accordance with NRS-3.

II. REFERENCES:

NRS-3, "Specification for Uranium Dioxide Pellets"

Arthur J. Rosenberg, "The Rapid, Precise Measurement of Krypton"
Adsorption and the Surface Area of Coarse Particles," J. Am. Chem. Soc.
78, 2929 (1956)

III. SAMPLE:

A sample of 2% of the finished pellets will be inspected for BET surface area in accordance with this specification.

IV. METHOD OF ANALYSIS:

- a. The BET surface area shall be determined by the krypton adsorption method as described in the References. An alternate method of analysis may be used if approved by the Company.
- b. A test run shall consist of approximately sixteen pellets that have been ground to size, washed, and dried.
- c. Standard samples will be furnished to the Seller by the Company for qualification of the Seller's procedure for measuring BET surface area on finished pellets. Qualification of Seller's procedure shall be a condition of acceptance of the pellets by the Company.

V. ACCEPTANCE OR REJECTION:

If the BET surface area of the sample exceeds $25 \text{ cm}^2/\text{g}$, all the pellets representing that sample shall be rejected unless the Seller performs additional analyses sufficient to assure a 95-95% confidence level that the pellets are within the limits specified.

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APPENDIX B

Drawings

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ORNL-DWG 65-8483

NOTES:

1. SEE SPEC. NRS-1 FOR ASSEMBLY, FABRICATION AND WELDS.
2. ASSEMBLED FUEL ELEMENT TO BE STRAIGHT WITHIN 0.030 in./3 ft LENGTH.
3. THE MAXIMUM WELD BUILD UP (ROLL OVER) ON THE UPPER END CAP WELD SHALL BE 0.510-in. OD.

ENG. DWG. C-108-80

ASSEMBLY, FUEL ELEMENT

$19\frac{7}{8} \pm \frac{1}{64}$

NOTES:

1. TUBE TO BE STRAIGHT WITHIN 0.030 in./3 ft OF TUBE LENGTH
2. TUBE ENDS TO BE SQUARE TO OD WITHIN 0.002-in. TIR
3. SEE SPEC. NRS-2

ENG DWG B-108-79

TUBE

ORNL-DWG 65-8485

0.500-in. OD NOM

ID = 0.460 ± 0.001 in.

WALL = 0.020 ± 0.002 in.

ENG DWG B-108-87

SUBASSEMBLY, TUBE

SECTION THROUGH SPACERS

DETAIL OF SPACER

NOTES:

1. 0.560-in. DIAM TO BE CONCENTRIC TO OD OF TUBE WITHIN 0.003-in. TIR
2. ONE SPACER AT EACH STATION (6¹/₄ in., 12¹/₄ in., AND 18¹/₄ in.) SHALL BE IN ALIGNMENT WITHIN 1°-0' OF THE ϕ OF 0.0635-in. HOLE IN END CAP.

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ORNL-DWG 65-8492

END CAP (UPPER)

NOTES:

1. 0.125-in.-DIAM HOLE AND 0.462-in. DIAM TO BE CONCENTRIC WITHIN 0.002-in. TIR
2. SURFACE "A" TO BE PERPENDICULAR TO 0.125-in.-DIAM HOLE WITHIN 0°-15°
3. MAXIMUM SURFACE ROUGHNESS NOT TO EXCEED 125 rms UNLESS OTHERWISE SPECIFIED
4. BREAK ALL SHARP EDGES
5. SEE SPEC. NRS-7

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ORNL-DWG 65-8493

* 22 END CAPS HAD HOLES WHICH WERE OFF THE CENTER BY 0.0015 in. AND 15 WERE OFF BY 0.0020 in.

NO. 52 (0.0635 in.) DRILL THRU. TO BE WITHIN 0.001 in. OF TRUE POSITION ON ϕ *

NOTES:

1. 0.462-in. DIAM AND 0.226-in. DIAM TO BE CONCENTRIC WITHIN 0.001-in. TIR
2. SURFACE "A" TO BE PERPENDICULAR TO 0.229-in. SHAFT WITHIN 0°-05'
3. MAXIMUM SURFACE ROUGHNESS NOT TO EXCEED 125 rms UNLESS OTHERWISE SPECIFIED
4. BREAK ALL SHARP EDGES
5. SEE SPEC. NRS-7

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ENG. DWG. A-108-82

UO₂ PELLETT

NOTES:

1. ENDS OF PELLETT ($\frac{1}{4}$ -in. DIAM) TO BE SQUARE WITH OD WITHIN 0.005-in. TIR.
2. SEE SPEC. NRS-3.

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ORNL-DWG 65-8489

ENG. DWG A-108-83

MgO PELLET

NOTES:

1. ENDS OF PELLET TO BE SQUARE WITH OD WITHIN 0.005-in. TIR.
2. SEE SPEC. NRS-4.

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ORNL-DWG 65-8487

ENG DWG A-108-84

BeO PELLET

NOTES:

1. ENDS OF PELLET TO BE SQUARE WITH OD WITHIN 0.005-in. TIR.
2. SEE SPEC. NRS-5.

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ORNL-DWG 65-8486

ENG. DWG A-108 - 85

$\text{Gd}_2\text{O}_3 - \text{Al}_2\text{O}_3$ PELLETS

NOTES:

1. ENDS OF PELLETS TO BE SQUARE WITH OD WITHIN 0.005-in. TIR.
2. SEE SPEC. NRS-6.

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ORNL-DWG 65-8490

WIRE DIAM = $0.050^{+0.000}_{-0.003}$ in.

ACTIVE TURNS = 40

NOTES:

1. MATERIAL AS PER SPEC NRS-8
2. BOTH ENDS GROUND TO PROVIDE A GOOD BEARING SURFACE

*ABOUT HALF OF THE SPRINGS WOULD NOT MEET THIS FREE LENGTH

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ORNL-DWG 65-8494

NOTES:

1. 0.110-in.-DIAM SHAFT AND 0.445-in.-DIAM PISTON TO BE CONCENTRIC WITHIN 0.002-in. TIR
2. SURFACE "A" TO BE PERPENDICULAR TO PISTON AND SHAFT WITHIN 0°-05'
3. MAXIMUM SURFACE ROUGHNESS NOT TO EXCEED 125 rms UNLESS OTHERWISE SPECIFIED
4. SEE SPEC. NRS-7

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ENG. DWG A-108-86

UO₂ WEIGHT-LENGTH TOLERANCE

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ORNL-DWG 65-8494

PROTOTYPE END-CAP, LOWER

NOTES:

1. SURFACE "A" TO BE PERPENDICULAR TO 3/32-in. SHAFT WITHIN 0°-15'
2. MAXIMUM SURFACE ROUGHNESS NOT TO EXCEED 125 rms UNLESS OTHERWISE SPECIFIED
3. BREAK ALL SHARP EDGES
4. SEE SPEC. NRS-7

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APPENDIX C

Westinghouse's Procedures and Forms

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INTRODUCTION

With the exception of Procedure No. 5, the following procedures were written by Westinghouse's personnel and modified slightly to fit into the style and format of this report. Procedure No. 5 was written by Aerobrazo, a subvendor of Westinghouse. These procedures were written in compliance with the requirements of the NRS specifications. These procedures were all reviewed and approved by appropriate ORNL personnel.

Numerous forms were used to record the data on the MPRE fuel element. The only form presented is the one used to record the assembly data on each fuel element. By using these forms, one can obtain the complete manufacturing and inspection history of each fuel element.

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Procedure No. 1

DRYNESS TEST FOR THE UO_2 PELLETS USED IN THE MPRE FUEL ELEMENTS

SCOPE:

This procedure is to define the method for determining dryness of ORX pellets per paragraph X A4 of NRS-3.

EQUIPMENT:

1. Analytical balance.
2. Vacuum drying oven.
3. Dry nitrogen - commercial plus magnesium perchlorate, dried.
4. Vacuum pump.
5. McLeod gage.

PROCEDURE:

1. Weigh a group of pellets (10 or more) individually on the analytical balance to accuracy of 0.1 mg.
2. Add all weights together and record as starting weight. Place pellets on wire screen basket and put in oven.
3. Evacuate oven to 29 in. vacuum. Flush with dry nitrogen to 3 in. vacuum. Repeat pumping and flush two more times.
4. Turn on vacuum oven when vacuum is at 29 in. on third flush.
5. Check vacuum with McLeod gage and make certain it remains less than 1 mm Hg.
6. Hold temperature at 250°C 4 hr and turn off.
7. Turn off vacuum and increase pressure to 3 in. vacuum with dry nitrogen.
8. When pellets are cool, weigh complete as in 1.
9. Determine ppm moisture in pellets by $\frac{\text{wt in 1} - \text{wt in 8}}{\text{wt in 1}} \times 10^6 =$ ppm moisture.

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Procedure No. 2

THERMAL CYCLE TEST OF $Gd_2O_3-Al_2O_3$ PELLETS
FOR MPRE FUEL ELEMENTS

1. Heat pellets in air in a furnace operating at $1475 \pm 25^\circ F$ for for at least the time necessary for the pellets to reach the same color as the interior of the furnace as judged by eye. As an alternative, pellets may be placed in a cold or warm furnace and the furnace then raised in temperature to $1475^\circ F \pm 25^\circ F$.
2. Remove pellets from furnace and quench immediately in a container of cold tap water.

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Procedure No. 3

WELDING THE LOWER AND UPPER END CAP ON THE MPRE FUEL ELEMENT

1. Measure OD of tube at the end plug. Select the copper chill that is 0.0005 to 0.001 in. larger than the OD of the tube.
2. Place tube in collet.
3. Adjust the tube so the top of the chill and the top of the tube are at the same level.
4. Brush away evidences of copper particles.
5. Place purge chamber in position (only for lower end cap) and adjust He flow.
6. The tube is welded at the following parameters:

Current - 22 to 26 amp
Starting impulse - 28 amp max
Arc length - 0.020 in.
Rotation - 16 rpm
Weld time - 8 sec
Taper time - 1.5 sec

Electrode is placed at interface between tube and end plug.

7. Brush evidences of discoloration or contamination with stainless steel brush.
8. Record tube number on voltage and current recorder charts beside its respective trace.

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WELDING THE FINAL CLOSURE WELD ON THE MPRE FUEL ELEMENT

1. Clamp retort to weld box.
2. Pump down the weld box and the retort to 0.5 μ . The door of the retort will pop open.
3. Back fill with helium to 1 atm pressure.
4. Swing door open, pull out the welding fixture, and lock in position.
5. The weld parameters are as follows:

Current - 14 to 20 amp
Arc length - 0.030 in.
Weld Time - 0.5 sec

An 80% He and 20% Ar purge is used to start the arc.

Place electrode in the center of the hole to be welded shut.

6. Pump down box to 6 to 8 psi (12.2 to 16.1 in. Hg).
7. Weld all rods.
8. Open weld box.
9. Brush away evidences of discoloration or contamination with a stainless steel brush.
10. Record the tube number on voltage and current recorder charts beside its respective trace.

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Procedure No. 5

BRAZING THE SPACERS TO THE MPRE FUEL ELEMENT

1. Clean all parts in acetone. Operator to wear white gloves.
2. Assemble parts in assembly fixture ORX G3 (B in Fig. 7).
3. Set condenser discharge to full capacity. Weld all 18 spacers, 4 tacks per spacer.
4. Check all spacers with go no-go gage using the ORX G1 gage (L in Fig. 7).
5. Apply Nicrobraz No. 50 alloy around joint. Wipe alloy into joint. Remove all excess alloy. Operator to wear white gloves.
6. Hang in retort in vertical position. Attach 4 thermocouples per load as shown in sketch.

7. Preheat furnace to approximately 1700°F on furnace control instrument.
8. Purge retort for 45 min with 150 cfh H₂. Dew point to be -65°F or better.
9. Heat to 1600°F high temperature and hold for all thermocouples to stabilize. When the thermocouples have reached 1650°F ± 15°F, heat part to 1900°F ± 25°F for 3 to 5 min.
10. Remove retort from furnace as fast as possible, cool to 400°F and purge.

NOTE: Part not to remain above 1800°F for more than 18 min.

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Procedure No. 6

CHECKING MOISTURE IN UO_2 AFTER LOADING INTO THE
MPRE FUEL ELEMENTS

EQUIPMENT:

CEC No. 26-321A Solids Moisture Analyzer - set up and calibrated per manufacturer's instructions.

PROCEDURE:

Pellets for dryness determination will be run through normal retort drying in a dummy fuel rod. After removal from the weld box, the end will be sealed closed until analysis.

ANALYSIS:

1. Sample randomly three two-pellet samples from the dummy rod. Store in sealed bottle until analyzed.
2. Insert a two-pellet sample into the furnace of the 26-321A moisture analyzer. Set temperature for maximum ($300^{\circ}C$) for 20 min to 1 hr. After no further counts are obtained, record the total counts.
3. Remove pellets from oven and weigh both together.
4. Run blank on analyzer by opening the furnace for the time required to insert a sample and otherwise following step 2 but using no sample.
5. Calculate ppm moisture:

$$\frac{\mu g \text{ H}_2\text{O in sample} - \text{blank}}{\text{Sample wt in g}} = \text{ppm moisture.}$$

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Procedure No. 7

X-RAY PROCEDURE FOR INSPECTION OF WELDS ON
THE MPRE FUEL ELEMENTS

1. End Plug to Tube Weld X-Ray Procedure.
 - A. 250 kv industrial x-ray machine.
 - B. Fixed focal distance - 48 in.
 - C. Kodak type "M" Ready Pak film.
 - 1) The film will be tapped toward the edge of the film package and fastened so the weld will not be superimposed upon the edge of the film containing the film manufacturer's identification.
 - D. A 0.005-in.-thick penetrameter, containing 0.005- and 0.010-in.-diam holes, will be fastened on top of a stainless steel block to make the following thicknesses: 0.020, 0.047, and 0.083 in.
 - E. Welds and film will be positioned approximately 2 in. off center of the x-ray tube head center line.
 - F. A light film (for the 0.020- and 0.047-in. thicknesses) and a dark film (for the 0.047- to 0.083-in. thickness) will be taken at each location on the weld.
 - G. Each weld will be exposed to 0, 90, 180, and 270° around the circumference and the film and rod identified as follows:
1 = 0°, 2 = 90°, 3 = 180°, and 4 = 270°.
 - H. Exposures will be as follows:
130 kv, 10 ma, 1 1/4 min for the 0.020- and 0.047-in. thicknesses.
175 kv, 10 ma, 45 sec for the 0.047- to 0.083-in. thicknesses.
 - I. Sketch of layout technique:

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J. Film identification

Film number (lot number) and prefixed with ORX.

SN End = Rod serial number end (long end plug)

OPP End = End opposite the serial number (short end plug)

A = Exposure for 0.020- to 0.047-in. thicknesses

B = Exposure for 0.047- to 0.083-in. thicknesses

1 = Exposure for 0° of weld

2 = Exposure for 90° of weld

3 = Exposure for 180° of weld

4 = Exposure for 270° of weld

R = A re-x ray

Rod location will be numbered from top (No. 1) to bottom of film (No. 25). Example of x-ray lot number and position on record sheets

101-5 = Lot or film No. 101, rod is at position No. 5 on x-ray film.

2. TIG Weld (Opposite serial number end of rod)

A. 250 kv industrial x-ray machine.

B. Fixed focal distance - 48 in.

C. Kodak type "M" Ready Pak film.

1) The film will be tapped toward the edge of the film package and fastened so the weld will not be superimposed upon the edge of the film containing the film manufacturer's identification.

D. A 0.005-in.-thick penetrometer, containing 0.005- and 0.010-in.-diam holes, will be fastened on top of a stainless steel block to make a thickness of 0.125 in.

E. Welds and film will be positioned approximately 2 in. off center of the x-ray tube head center line.

F. Each weld will be exposed at 0 and 90° around the circumference.

G. Exposure will be 195 kv, 10 ma, 50 sec.

H. All rods will be positioned on x-ray film in the same location as they were for the end plug to tube weld.

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I. Sketch of layout technique

J. Film identification

Film number to be the same as for end plug welds. (Rods will be kept in x-ray lots.)

The 0° exposure of the weld will not be marked as such; however, the 90° exposure will be identified with a 9.

All film will be identified with the letters TIG. Rod locations are numbered from 1 to 25 starting from top of film and will be in the same orientation as was used for end plug weld.

3. Full Length of Rod.

- A. 250 kv industrial x-ray procedure.
- B. Focal distance is 42 in.
- C. Kodak type "M" film used in film holders.
- D. Two films will be exposed for each half of the fuel rod and the film from one end to the other shall overlap by 1 in. minimum.
- E. Exposure shall be as follows: 160 kv, 10 ma, 1 min.
- F. Sketch of layout as follows:

Note: No filter will be used at the tube head.

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Rod Loading & Inspection Report
Data Sheet

WESTINGHOUSE ELECTRIC CORP.
Atomic Power Div.

Project MPRE
Rod No. _____

Westinghouse Form FM&D-0020

	Gd ₂ O ₃ - Al ₂ O ₃	BeO	MgO	UO ₂	TOTAL	BOTTOM END PLUG Lot No.	TOP END PLUG Lot No.	PLUNGER Lot No.	SPRING Lot No.	BRAZE Lot No.	NO BRAZE	TUBE Lot No.
Lot No.												
Weight						BOTTOM END PLUG Heat No.	TOP END PLUG Heat No.	PLUNGER Heat No.	SPRING Heat No.	SPACER Heat No.	SPACER Heat No.	TUBE Heat No.
Length												
												
	LEAK TEST	X-RAY Lot No.	X-RAY VIEWING	DECREASING	ZYGLO	DIMENSIONS	X-RAY Lot No.	X-RAY VIEWING FINAL DISPOSITION	REPAIR			
1												
2												
3												
4												
5												
6												
SIGNATURE & DATE		ACC.	REJ.	REP.	SCRAP	COMMENTS SUPPORTING DISPOSITION (DATA ATTACHED ☐)						
QUALITY CONTROL												
ENGINEERING												
QUALITY CONTROL ENG.												

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