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Records

WANL-TME-2788
MAY 1971

SUMMARY FABRICATION REPORT
FOR PEWEE-2 FUELED ELEMENTS
(U)

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SUMMARY FABRICATION REPORT

FOR PEWEE-2 FUELED ELEMENTS

(U)

APPROVED BY:

G.R. Kilp

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(CRD) ABSTRACT (U)

(U) The production of components for the Pewee-2 reactor by Westinghouse Astronuclear Core Operations at Cheswick, Pennsylvania, began with fuel extrusions on June 27, 1969. Shipment of all prime and experimental elements for the core was completed on schedule on July 3, 1970.

(CRD) This fabrication campaign began without preproduction and with two new high expansion graphite flours: AXM for the standard elements and AXF for the experimental elements. In addition to these new materials, several new or modified processes were used including:

- Argon purge during cure and bake.

- Pre-braze O.D. machining and leaching.

- Braze of composite tip directly to the fuel element.

- HCl leach at 2100°C.

- Duplex coating with NbC GEM/ZrC HED for standard elements.

- Duplex coating with NbC GEM/ZrC GEM for experimental elements.

- Dry atmosphere protection beginning after leach for hydrolysis protection.

(U) Concurrent with these new processes, procedures were modified to include:

- Substitution of MULE for BBS to determine bore coating profile.

- Electrical resistance measurements of every element before and after coating.

- New or revised systems for leak test, air impedance, and gamma count measurements.

(U) Moreover, all UCCND (Y-12) fabricated elements were coated at WNCO because the Y-12 coating process would not meet the corrosion test requirements.

(U) In addition to the fuel effort, all ordered quantities of support hardware for the Pewee-2 core and associated test programs were coated and shipped.

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1.0 (CRD) INTRODUCTION (U)

(U) The fabrication campaign for the Pewee-2 reactor at Westinghouse Astronuclear Core Operations began on June 27, 1969, with the extrusion of fuel elements. Both core prime and experimental elements as well as standard and experimental hardware were delivered on schedule.

(CRD) In addition to the use of two new graphite flours, AXM for the standard elements and AXF for the experimentals, a number of new processes and inspection procedures were utilized. These new processes included a) argon purge during cure and bake, b) pre-braze machine and leach, c) braze of composite tip* directly to the fuel element and automatic control of the braze cycle, d) HCl leach at 2100°C, e) dry atmosphere protection after leach for hydrolysis control, and f) two new duplex coating processes.

(U) The Quality Control procedures were modified to include a) substitution of MULE for beta backscatter to determine bore coating profiles, b) electrical resistance measurements of every element before and after each coating operation, and c) new or revised systems for leak test, air impedance, and gamma count measurements.

(U) This report documents the fabrication of Pewee-2 with discussions not only of these processing and Quality Control procedures but also of the ordering information and schedular aspects of the program.

* (CRD) In this report the designation 75/25 refers to tips made from a composite of NbC and graphite in the proportions 75 w/o NbC and 25 w/o free carbon. Similarly, 65/35 refers to 65 w/o NbC and 35 w/o carbon.

2.0 (CRD) PROGRAM REQUIREMENTS (U)

2.1 (U) Fuel Element Schedules (U)

(U) Fabrication of the Pewee-2 elements began with fueled extrusions the week of June 27, 1969. Processing of elements through subsequent steps of manufacture included coordination of the combined efforts of WNCO, UCCND (Y-12), and WANL to accomplish the desired matrices. Coating at WNCO began on January 24, 1970, and was completed on June 19, 1970. Schedules of extrusion through final inspection, certification, and delivery were maintained throughout the period. Final inspection and final shipment of all prime and experimental fuel elements was completed on schedule on July 3, 1970.

2.2 (CRD) Fuel Elements (U)

(CRD) Ordering of fuel elements from WNCO for Pewee-2 was accomplished by work orders prepared by WANL Production Control. A brief summary of shipments for all Pewee-2 and related efforts is given below:

<u>Quantity</u>	<u>To</u>	<u>Purpose</u>
302	LASL	Core + Spares
30	LASL	As Graphitized for LASL "Hybrid" Graphite/Composite Experiment
74	LASL	LASL MULE, TDT/TDL, Q ^{III} , 00DM316, FOX, and Mechanical Properties
99	WANL	Corrosion Test + Hydrolysis Evaluation
54	WANL	Chemistry, QIP-52 Requirements, Mechanical Properties
<u>102</u>	WANL	Component Test (66DT248, 66DT251, 00DE102, 00DM175)
661	TOTAL	

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(U) Table 2-1 is a detailed summary of the Pewee-2 core effort. This tabulation indicates the type of element, pertinent WANL drawing, processing suppliers, order number and quantities, number of applicable change notices against original order, and some description of the element matrix, coating, and geometry.

(U) The basic work orders included coating of elements received from UCCND (Y-12) in the "as-leached" condition. The supplier for finished elements was designated by "Manufacturer through leach - Manufacturer after leach," i.e., W-W, Y-W*.

(U) Table 2-2 summarizes the biweekly progress from extrusion through shipment of core candidate elements and special elements. Table 2-3 summarizes overall process yields by process stage for core and related sample candidate elements. In addition to core candidates, elements were shipped for required test samples, component tests, or other evaluations. Table 2-4 is a detailed summary of the non-core candidate effort.

(U) During the course of the manufacturing campaign, tip brazing and coating process and test anomalies were identified. When receipt of tip brazing process approval was delayed, a decision was made to ship elements to UCCND (Y-12) for brazing. An extensive effort was initiated to prepare and ship elements for tipping and to this end, eighty-eight (88) WNCO elements were shipped to UCCND (Y-12). Subsequent to this shipment, the WNCO process was approved and no further shipments were made. The 88 elements were tipped by UCCND (Y-12) and returned to WNCO for further processing.

(U) When UCCND (Y-12) was unable to meet the Pewee-2 corrosion test requirements, a decision was made to minimize schedular perturbations by having WNCO coat 211 elements including those processed from extrusion through leach by UCCND (Y-12). WNCO demonstrated the compatibility of coating the Y matrix and as a result, 195 "as-leached" elements were received from UCCND (Y-12) and coated at WNCO.

* (U) W - Westinghouse Astronuclear Laboratory

Y - UCCND (Y-12)

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(U) The identification of coating nodules in the bores of WNCO coated elements required an extensive program to identify cause and corrective actions. From early December, 1969, to mid January, 1970, a total of thirty-six (36) previously unscheduled coating runs were made to investigate and attempt to eliminate bore coating nodules. During this time period, bore coating of all core candidates was delayed.

2.3 (U) Hardware (U)

(U) In addition to element manufacturing, WNCO processed prime and experimental reactor hot end support hardware. Table 2-5 lists type, style, pertinent WANL drawing, order number, number of applicable change notices against the original order, quantities processed and shipped for final WANL evaluation, and yield ratios of quantities processed to quantities shipped.

TABLE 2-1
(CRD) ORDERING SUMMARY - CORE ELEMENTS (U)

Code	Drawing & P/N	Processing Suppliers	Order	Last C/N	Quantity		Coating Variable	Bore Variable	Length Back Coat	Tip Length (Type)	Composite (Lgth.)	Matrix Variable	End Use
					Ordered	Delivered							
521	939J023G69H	W-W	06640	68	15	15	NbC/GEM	102	3-4"	75/25 tip	.370	AXM	Core Prime
473	939J023G70H				15	15	ZrC/HED	102					
430	939J023G71H				14	14		102					
391	939J023G72H				27	27		102					
355	939J023G73H				33	33		102					
323	939J023G74H				21	21		102					
293	939J023G75H				46	46		102					
267	939J023G76H				27	27		102					
243	939J023G77H				9	9		102					
473	939J023G16H				14	14		102		65/35 tip			
521	939J709G01C	Y-W	17733	12	12	3		105		65/35 tip		AXF	Core Exper.
521	939J709G02C				12	9		105		65/35 tip		AXF pyro impreg.	Core Exper.
630	939J023G78J				46	47		102		75/25 tip		AXF	Core Prime
573	939J023G79J				15	16		102		75/25 tip		AXF	Core Prime
630	939J708G01B				6	6		102		75/25 tip		AXF	Core Exper. (wafer)
391	939J023G78J	W-W	06640	68	12	0	-	-	-	-	-	SMC-2	Cancelled

TABLE 2-2
 (CRD) BI-WEEKLY SUMMARY OF FUEL ELEMENT MANUFACTURING (FULL LENGTH ELEMENTS ONLY) (U)

Week Ending	Extrude			First Machine			ZrC HED Coat				Final Machine				Final Inspection				Ship			
	Prime	Exp.	Compt.	Prime	Exp.	Compt.	Prime	Exp.	Compt.	Y-W	Prime	Exp.	Compt.	Y-W	Prime	Exp.	Compt.	Y-W	Prime	Exp.	Compt.	Y-W
6/27/69	71																					
7/11/69	152																					
7/25/69	437																					
8/8/69	85	25	105																20			
8/22/69			19																			
9/5/69																						
9/19/69																						
10/3/69																						
10/24/69				90																		
11/7/69				128																		
11/21/69				188																		
12/5/69				58																		
12/19/69	22	159		116																		
1/2/70				48																		
1/16/70				2	47	42																
1/30/70				28		78																
2/13/70					49		35															
2/27/70							70				8											
3/13/70							175				27				8							
3/27/70							35				100				50							
4/10/70							35				75				47							
4/24/70							175				110				140							
5/8/70		18					55	35	10		130				175							
5/22/70									95		120		60		105							
6/5/70								35		140					45		60					
6/19/70										50						20	140	151	10			
7/3/70											70	25	140	50	70	25	35	70	12		69	
7/17/70																	15					
7/31/70																						
8/14/70																						
8/28/70																						
9/11/70																						
Total	767	202*	124	658	96	120	580	70	105	190	570	70	105	190	570	70	105	190	221	54	35	97

* Includes (61) SMC-2 and LASL Hybrid Exp. (43) ** Ship to WANL 66DT248 and 66DT251

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TABLE 2-3

(U) FINAL YIELDS OF W-W PRIME CORE CANDIDATE ELEMENTS (U)

Process Stage	No. of Elements Thru Stage	Yield to Work Order
Extrude and Cure	767	2.09
Bake	767	2.09
Graphitize	767	2.09
Pre-Tip Machine	714	1.95
Tip	706*	1.92
First Machine	658	1.79
First Inspection	658	1.79
Leach	644	1.75
Leach Inspection	644	1.75
Nb Coat	583	1.58
Nb Inspection	583	1.58
Q Coat	580	1.57
Q Inspection	577	1.56
Final Inspection	570	1.55
Ship to LASL (Core)	221	1.00
Ship to LASL (Samples & ele.)	55	1.00
Ship to WANL (Spec. samples)	33	1.00
Ship to WANHES (Core test)	56	1.00

* Included W-W elements tipped at Y-12.

TABLE 2-4
(CRD) ORDERING SUMMARY - ELEMENTS AND SPECIMENS (U)

Code	Drawing & P/N	Processing Suppliers	Order	Last C/N	Quantity		Coating Variable	Bore Variable	Length Back Coat	Tip Length Composite		Matrix Variable	End Use
					Ordered	Delivered				Type	Length		
630	939J023G78J	Y-W	17733	12	1	1	NbC/GEM	.102	3-4"	75/25	.370	AXF	Mechanical Prop.(A.1.-1/3)
630	939J023G78J				17	17	ZrC/HED						Comp. tst. (as ct. specimen (00DE102 - 00DM175)
630	939J023G78J				3	3							"Q" tst. spec. (00DM316)
573	939J023G79J				3	3							"Q" tst. spec. (00DM316)
630	939J023G78J				16	16							R-1 compnt. tst. eval. (66DT248)
630	939J023G78J				10	10							R-1 compnt. tst. eval. (66DT251)
630	939J708G01B				2	2						AXZ	R-1 compnt. tst. eval. (66DT251)
521	939J023G69H	W-W	06640	68	1	1	as machined	as extruded	-	non-tipped		AXM	LASL MULE
391	939J023G72H				1	1	as machined	as extruded	-	non-tipped			LASL MULE
267	939J023G76H				1	1	as machined	as extruded	-	non-tipped			LASL MULE
267	939J023G76H				1	1	NbC/GEM	.102	3-4"	75/25	.370		TDT-TDL (ctd.)
521	939J709G02C				1	1	ZrC/HED	.105	3-4"			AXF-PyC	TDT-TDL (ctd.)
521	939J023G69H				1	1	Leached	.102	-			AXM	TDT-TDL (ready to coat)
430	939J023G71H				1	1			3-4"				
355	939J023G73H				1	1							
323	939J023G74H				1	1							
267	939J023G76H				1	1							
521	939J023H89H				6	6							00DM196 Mech. Prop.
521	939J023G69H				17	17	NbC/GEM						Comp. tst. (as ct. spec. (00DE102 - 00DM175)
							ZrC/HED						"Q" tst. spec. (00DM316)
243	939J023G77H				2	2							
267	939J023G76H				2	2							
293	939J023G75H				2	2							
323	939J023G74H				2	2							
355	939J023G73H				2	2							
391	939J023G72H				2	2							
430	939J023G71H				3	3							

TABLE 2-4 (CONT.)

(CRD) ORDERING SUMMARY - ELEMENTS AND SPECIMENS (U)

Code	Drawing & P/N	Processing Suppliers	Order	Last C/N	Quantity		Coating Variable	Bore Variable	Length Back Coat	Tip Length Composite Type Length		Matrix Variable	End Use
521	939J023G69H	W-W	06640	68	3	3	ZrC/HED	.102	3-4"	75/25	.370	AXM	"Q" tst. spec. (00DM316)
521	939J709G01C				2	2						AXF	
521	939J709G01C				2	2						AXF-PyC	
521	939J023G69H				18	18	NbC/GEM ZrC/HED					AXM	R-1 compnt. tst. eval. (66DT248)
521	939J023G69H				10	10							R-1 compnt. tst. eval. (66DT251)
521	939J709G01C				6	6						AXF	R-1 compnt. tst. eval. (66DT251)
521	939J709G02C				6	6							R-1 compnt. tst. eval. (66DT251)
166	939J023N/A				16	20	as graph	as extruded	-		non-tipped	AXM	LASL Hybred exp. #1
204	939J023H88M				10	10	as graph	as extruded			non-tipped	AXM	LASL Hybred exp. #2
521	939J709G01B				1	1	NbC/GEM ZrC/HED	.102	3-4"	75/25	.370	AXF	00DM196 mech. P (AI-1/3)
521	939J709G02B	Y-W	17733	12	1	1						AXF-PyC	00DM196 mech. P (AI-1/3)
521	939J023G69H				1	1						AXM	00DM196 mech. P (AI-1/3)
Chem.	PDS 30134				15	15				NF 1"			PDS 30134
QIP 52	PDS 30134				13	13	as leach		-	75/25	.370		PDS 30134
Ich													
QIP 52	PDS 30134				13	13	NbC/GEM ZrC/HED		3-4"				PDS 30134
ctd													
521	939J023G24F				2	2	as graph	as extruded	-		non-tipped		66DM304
521	939J023G69H				2	2	NbC/GEM ZrC/HED	.102	3-4"	75/25	.370		Proj. MGMT. Dir. (ctd)
Chem.	PDS 30134				6	6				NF 1"		AXF	PDS 30134
QIP 52	PDS 30134	Y-W	17733	12	3	3				75/25	.370		PDS 30134
-	939J023				-	4							LASL Hot Gas Test
-	939J023				-	6						AXM	LASL Hot Gas Test
-	939J023				-	9						AXM	FOX
-	939J023				-	4						AXF	FOX

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(U) HOT END HARDWARE (U)

Type	Style	WANL Drawing	Order	Last C/N	Quantity Processed	Quantity Shipped	Processed/Shipped Rate
Pedestal	75/25	929F033 G03E	77470	4	86	46	1.87
Pedestal	65/35	929F033 G02E	77471	5	59	29	1.96
Cup	Outer(S) 75/25	981D352 H03B	13195	2	59	43	1.37
Cup	Outer(S) 65/35	981D352 H02B	13196	2	35	25	1.4
Cup	Outer(L) 75/25	981D352 H06A	13195	1	30	13	2.3
Cup	Outer(L) 65/35	981D352 H05A	13196	1	19	5	3.8
Cup	Inner(S) Pyro	981D355 H01	13193	2	66	33	2.0
Cup	Inner(L) Pyro	981D355 H02	13193	2	40	21	1.9
Sleeve	Outer H205	981D489 H02A	13197	1	176	83	2.11
PW-2 EXPERIMENTAL							
Tip Extensions	65/35	981D495 H01A	00580	2	43	36	1.2
Cup	Outer 65/35	981D493 H01A	00578	1	30	24	1.25
Cup	Inner Pyro	981D491 H01A	00579	1	26	12	2.17
TS 009DE191							
Tip Extensions	65/35	981D495 H01A	00580	2	13	11	1.2
Cup	Outer 65/35	981D493 H01A	00578	1	9	7	1.3

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3.0 (CRD) FABRICATION (U)

3.1 (CRD) Materials (U)

(U) Two new high expansion graphite flours were used in the fabrication of Pewee-2 fueled elements. These two graphites were designated as AXM, used in the standard elements, and AXF, used in the experimental elements.

(U) The AXM designated flour was ground at UCCND (Y-12) from material purchased by SNSO from the POCO Carbon Company.

(U) The AXF designated flour was ground at WNCO from material purchased by WNCO from the POCO Carbon Company.

(CRD) The Pewee-2 fueled elements were fabricated with 82 parts of cross-blended flour to 18 parts of carbon black, Gulf-General Atomic fuel beads and furfuryl alcohol "Varcum" catalyzed with maleic anhydride.

(CRD) The AXM fueled elements required 28 percent "Varcum" while the AXF fueled elements required 33 percent in order to produce acceptable elements.

(CRD) AXZ designated material purchased from POCO Carbon Company by and ground at WNCO was used for manufacturing non-fuel tip handles. This AXZ flour combined with thermax in an 85/15 ratio required a catalyzed Varcum level of 37.5% to produce acceptable elements.

3.2 (U) Batch Formulation (U)

(U) Batch formulation aim fuel loadings of graphitized elements were calculated by the carbon/uranium balance procedures utilized previously. However, the standard elements did not shrink as anticipated resulting in an approximate 2 percent lower final uranium loading than the aim. Corrections for this anomaly could have been made, if the schedule had permitted a preproduction effort. Uranium loading specification and final results are summarized in Table 3-1 and a correlation of uranium loading and permeability is shown in Table 3-2.

3.3 (CRD) Mix and Extrude (U)

(U) The mixing and extrusion processes were similar to those used for NRX-A6 and Pewee-1 fueled elements.

(CRD) The nominal tonnage for the AXM production run was 116 tons at 100 inches/min while the AXF experimental run was 101 tons at 100 inches/min.

3.4 (CRD) Cure (U)

(CRD) The curing temperature cycle remained the same as for NRX-A6 and Pewee-1. The cure trays, however, were enclosed in a sealed metal box which was purged with argon gas during the cycle.

3.5 (CRD) Bake (U)

(CRD) The bake cycle was the same as for NRX-A6 and Pewee-1 except an argon gas purge was used during the entire cycle eliminating the vacuum portion of the run.

3.6 (CRD) Graphitize (U)

(CRD) The elements were graphitized for 3 hours at 2200°C under an argon atmosphere and examined metallographically for fuel bead damage. All runs were accepted, except for a set of experimental Santa Maria Coke experimental elements. These latter elements experienced excessive migration due to impurities in the SMC flour.

3.7 (CRD) Tip Braze (U)

(CRD) Fabrication of the Pewee-2 elements eliminated the unfueled transition piece that was utilized in Pewee-1 to braze the composite hot end tip. The "transition tip" although still supplied as a unit to WNCO was turned around and the composite section brazed directly to the fueled element.

3.7.1 Joint Leak (U)

(CRD) All brazed joints (735) passed the 10 cc/min maximum leak rate except for 56 that were less than 35 cc/min and 6 that were greater than 35 cc/min.

3.7.2 Braze Modifications (U)

(CRD) Several modifications from the Pewee-1 tip brazing procedure were incorporated into the Pewee-2 process. These modifications are listed below:

- (CRD) a. All elements were pre-machined to 0.770 inch across flats and brazing furnace fixturing modified to obtain better alignment between tip and element.
- (CRD) b. An aqueous leach system employing concentrated HNO_3 acid was designed and built to leach the exposed uranium from the face of the fuel element to be brazed. The unit accommodated 45 elements and all elements were leached prior to brazing.
- (CRD) c. A pressure sensitive molybdenum tape approximately 1 mil thick was applied under pressure to the composite face of the tip. This application gave more uniform and consistent brazed joint than the previous powder technique.
- (CRD) d. A new RF coil was designed and built to give a more uniform heat distribution between the composite tip and the graphite element and also less damage to the fuel beads from the brazing temperature.
- (CRD) e. The temperature versus time parameters of the brazing cycle were automatically controlled by a temperature programmer unit that regulated the RF current output of the generator.

3.7.3 Cyclic Testing (U)

(CRD) An additional specification requirement for qualification of the brazed joint was employed for Pewee-2. This new requirement was a thermal cycling test of 15 cycles of 10 minutes duration at a surface temperature of 4700°R . Same difficulties were encountered in the testing for this requirement. The use of a susceptor rather than a direct coupling heating method proved to be the most significant change made to alleviate the problem. Although the final brazed joint cycling requirement was 15 cycles/ten minutes at 4700°R /three minute ramps, several other samples were successfully cycled at 4900°R and 5000°R .

TABLE 3-1
(CRD) URANIUM LOADING (U)

Loading mg U/cc	Specification Loading g/in	Final Loading	
		Range g/in	Average g/in
AXM PRODUCTION			
521	2.86	2.18-2.99	2.81
473	2.60	2.44-2.62	2.54
430	2.36	2.28-2.36	2.32
391	2.15	2.04-2.20	2.10
355	1.95	1.85-2.03	1.92
323	1.78	1.70-1.76	1.73
293	1.61	1.34-1.60	1.56
267	1.47	1.40-1.49	1.43
243	1.33	1.27-1.34	1.30
AXF EXPERIMENTAL			
521	2.86	2.72-3.01	2.86

TABLE 3-2

(CRD) WHOLE BODY LEAK RATE (AS-LEACHED) (U)

Uranium Loading mg/cc	Whole Body Leak Rate *	
	Average cc/min	Range cc/min
AXM		
521	60	12-230
473	120	48-380
430	105	25-220
391	69	14-460
355	59	14-680
323	72	18-200
293	59	10-380
267	51	14-200
243	44	10-190
AXF		
521	75	28-160

* Specification limit 170 cc/min - accepted by VR to maximum of 200 cc/min.

3.8 (CRD) Leach (U)

(CRD) The leaching process for Pewee-2 was changed from that used for NRX-A6 and Pewee-1. The process gas stream remained a 50-50 mixture of HCl and argon. The thermal processing cycle consisted of the following steps:

- a. Heat to 2100°C .
- b. Hold for 1 hour at $2100 \pm 50^{\circ}\text{C}$.
- c. Leach for 1 hour at $2100 \pm 50^{\circ}\text{C}$.
- d. Leach for 3 hours while decreasing to $1900 \pm 50^{\circ}\text{C}$.
- e. Leach for 3 hours while decreasing to $1600 \pm 100 \pm 50^{\circ}\text{C}$.

(U) The leach weight loss was found to vary, within a loading code, with a specific fuel bead lot. These weight losses are summarized in Table 3-3.

3.9 (CRD) Hydrolysis Control (U)

(U) A "dry" air system was installed at WNCO to process Pewee-2 elements with a minimum of exposure to conditions which could promote hydrolysis of the fuel beads. All operations after leaching were accomplished with a minimum of exposure to "wet" air. Storage between operations was under a "dry" air purge or in a purified argon atmosphere.

(CRD) The system installed at WNCO provided air of less than 20 parts per million water by volume and consists of two units, one providing a low pressure purge to the storage vaults and the second providing high pressure air to stations throughout the production areas for purging the in-process storage carts.

3.10 (CRD) Coat (U)

(CRD) Drawing 939J023 defined the coating requirements of the Pewee-2 fuel elements as a GEM NbC basecoat with a HED ZrC overcoat. The profiles, weight, and dimensional requirements are shown in Table 3-4. The work that established these requirements was performed under Test Specifications 3012 and 3017 and reported in TME-2708, "Pewee-2 Duplex Coating Development," July 1, 1970.

TABLE 3-3
(CRD) LEACH WEIGHT LOSS SUMMARY (U)

Loading mg/cc	Fuel Lot	No. of Elements	Expected Loss (gms)	Actual Losses (gms)	
				Average	Range
243		30	5.2	4.83	3.4-5.7
	44223	4		5.45	5.2-5.7
	44291	7		4.59	3.4-5.2
	44292	8		4.85	4.5-5.2
	Tailings	11		4.74	3.7-5.2
267		63	5.4	5.50	5.0-6.0
	44288	4		5.70	5.5-6.0
	44311	35		5.52	5.0-5.9
	Tailings	24		5.42	5.0-5.7
293		115	6.0	6.05	5.4-7.5
	44290	62		6.17	5.7-7.5
	44291	21		5.60	5.4-7.5
	Tailings	32		6.09	5.5-7.2
323		76		6.51	5.3-8.1
	44255	57		6.43	5.3-7.8
	44285	2		8.05	8.0-8.1
	Tailings	17		6.62	6.0-7.0
355		98	6.8	7.16	6.3-8.2
	44290	21		7.18	6.9-7.6
	44297	30		7.34	6.8-7.8
	44304	22		7.17	6.3-7.5
	44321	4		6.38	6.3-6.5
	Tailings	21		7.17	6.7-8.2

TABLE 3-3 (CONT.)
(CRD) LEACH WEIGHT LOSS SUMMARY (U)

Loading mg/cc	Fuel Lot	No. of Elements	Expected Loss (gms)	Actual Losses (gms)	
				Average	Range
391		90	7.5	7.58	6.6-8.3
	44287	4		6.90	6.8-7.0
	44289	49		7.81	7.3-8.3
	44321	13		6.93	6.6-7.3
	Tailings	24		7.57	6.7-8.3
430		47	8.3	7.3	6.1-8.5
	44254	3		7.27	7.2-7.3
	44287	29		7.20	6.1-7.8
	Tailings	15		7.49	7.0-8.5
473		88		8.63	6.9-10.5
	44289	42		9.07	8.0-10.5
	44292	18		7.57	7.0-8.4
	Tailings	28		8.65	6.9-9.7
521		220	9.7	9.31	7.7-12.0
	44288	6		10.1	9.6-10.5
	44289	11		9.85	9.5-10.5
	44292	40		8.52	7.7-9.9
	44295	45		8.68	8.1-9.1
	44297	10		10.99	9.3-12.0
	44298	3		9.4	9.1-9.7
	44304	18		10.64	10.2-11.2
	44305	11		10.45	10.1-11.0
	44311	3		8.93	8.2-10.0
	44319	2		9.65	9.1-10.2
	Tailings	71		9.26	7.8-11.8

(CRD) The process outlines for these coating operations were presented in AR 30025. The main parameters from WNCO Process Outline 05-09-09 for GEM NbC coating and WNCO Process Outline 05-09-07 for HED ZrC coating are shown in Table 3-5. The actual process data (averages for each run) are shown in Table 3-6 for WNCO elements and in Table 3-7 for WNCO coated Y elements. Runs 1 through 16 supplied core candidate elements and Runs 16 through 20 supplied elements to satisfy various "scope-of-test" requirements. The Y elements were coated in Pewee-2 Runs 23 through 28.

(U) Two primary problems were encountered in coating the Pewee-2 elements: nodules in the bores and hot end coating dimensions.

(CRD) The first problem was experienced in an NbC GEM verification run. Because a potential corrosion problem would be created if a nodule was broken from the coating, an extensive investigation was conducted with the following results:

- a. Metallographic samples from these elements showed that the nodules were associated with fuel beads.
- b. The number and severity of nodules could be reduced, but not eliminated, by a number of methods (diffusion pre-coating was the most promising) prior to NbC GEM coating.
- c. Nodules were found to have always been present in elements coated by the GEM NbC process, but have not been shown to be detrimental to corrosion performance.

(U) Because of the latter, the coating processes for Pewee-2 were not changed but to minimize the potential of damaging the coating. The inspection procedures were revised to eliminate the use of bore probes. An inspection and testing plan based on this was submitted and approved, and a release was given to proceed with coating fuel elements.

(CRD) The second problem concerned the hot end external coating thickness and dimensions. The coating would exceed the thickness requirements at the extreme tip of the element, but rapidly fall to below the minimum at Station 49. This was related to a drop in the bore

TABLE 3-4
 (CRD) FUEL ELEMENT REQUIREMENTS AS-COATED (U)

1. Bore Coating Requirements

NbC GEM	
Station	Min. Thickness
0	0.5
10	1.5
15	1.8
52	1.8

ZrC HED	
Station	Min. Thickness
0	0.0
35	0.0
52	0.5

$$75 \pm 15 \text{ gr Nb} = 83 \pm 17 \text{ gr NbC}$$

$$13 \pm 8 \text{ gr Zr} = \text{Wt. gain during HED coating}$$

2. Back Coat and Across Flats

Total Back Coat Thickness	
Station	Min. Thickness
47-48.5	Flash Permitted
48.5-49	Visible
49	1.5
52	2.0
End Face	2.0

Station	Dimension
46	Reference
47-51.5	Ref. + 0.0003 Max.
49-52	Ref. - 0.0048 Min.
52	Ref. - 0.0008 Min.

3. Air Impedance

0.0935 Minimum As-ZrC Coated

TABLE 3-5
 (CRD) BASIC COATING PARAMETERS* (U)

<u>GEM NbC</u>	<u>GEM NbC</u>	<u>HED ZrC</u>
<u>Gas Flows (LPMPE)</u>		
Argon	1.81 ± 0.06	2.42 ± 0.06
Hydrogen	0.19 ± 0.002	0.33 ± 0.002
Anhydrous Hydrogen Chloride	0.64 ± 0.06	-----
Methane	0.041 ± 0.002	-----
Salt	0.089 ± 0.004	0.044 ± 0.004
<u>Temperatures ($^{\circ}\text{C}$)</u>		
No. 1 Sight Port	Record Only	Record Only
No. 2 Sight Port	$1060 \pm 10^{\circ}\text{C}$	$1750 \pm 10^{\circ}\text{C}$
No. 3 Sight Port	$1150 \pm 10^{\circ}\text{C}$	$1350 \pm 15^{\circ}\text{C}$
No. 4 Sight Port	$1290 \pm 10^{\circ}\text{C}$	$1100 \pm 50^{\circ}\text{C}$
Time (hrs.)	8.0 ± 1.0	20.0 ± 2.0

* GEM NbC - The above GEM NbC parameters were employed for Runs 1 through 8. Run 9 had the following temperature ($^{\circ}\text{C}$) changes: No. 2 S.P. = 1040 ± 10 ; No. 3 S.P. = 1150 ± 10 ; and No. 4 S.P. = 1270 ± 10 . Run 10 had the following temperature ($^{\circ}\text{C}$) changes: No. 2 S.P. = 1040 ± 10 ; No. 3 S.P. = 1135 ± 10 ; and No. 4 S.P. = 1270 ± 10 . Runs 11 through 20 had the following temperature ($^{\circ}\text{C}$) change: No. 2 S.P. = 1050 ± 10 .

HED ZrC - The above HED ZrC parameters were employed for Runs 1 through 3. Runs 4 through 20 had the following temperature ($^{\circ}\text{C}$) change: No. 2 S.P. = $1700 \pm 50^{\circ}\text{C}$.

coating thickness at the hot end brought about by a depletion of niobium in the coating gas stream. It was for this reason that temperatures were changed in Runs 9 and 10; however, although the bore coating profile changed, the change in the external coating thickness was not sufficient to justify changing the coating parameters. The addition of the ZrC HED coating brought the thickness above the minimum specification requirements.

(CRD) The thick NbC GEM coating at the extreme hot end led to the possibility that the final across flats dimensions would be too great. Therefore, the external surfaces at the hot end of the element were honed after NbC GEM coating to preclude this possibility before the final ZrC HED coating was applied.

3.11 (CRD) Experimental Elements (U)

(CRD) A heavy hot end coating experiment was designed for inclusion in the Pewee reactor. As defined in Drawing 939J709, the coating consists of a thin GEM NbC layer adjacent to the matrix and a heavy GEM ZrC coating over the NbC. The profiles, weights, and dimensional requirements are shown in Table 3-8.

(CRD) Two heavy hot end batches were coated for Pewee-2; one contained 0.105 bore AXF elements and the other contained PyC impregnated 0.105 bore AXF elements. The first batch (Pewee Run No. 21) had an inadequate backcoat due to salt depletion effects. The backcoat was extended in a short diffusion coating run. The second batch (Pewee Run No. 22) was coated with a higher salt flow and had an acceptable backcoat. The actual process data (averages for each run) are shown in Table 3-9.

TABLE 3-6
 (CRD) COATING RUNS (WNCO ELEMENTS) (U)

PW Run No.	NbC GEM Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Wt. Avg. gms.	ZrC Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Wt. Avg. gms.
		Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"				Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"		
1	T193	1.81	0.64	0.19	0.09	0.04	1060	1152	1293	8	97.4	M197	2.40	---	0.33	0.04	---	1106	1353	1752	20	9.1
2	L379	1.80	0.64	0.19	0.10	0.04	1063	1150	1292	8	98.7	M198	2.37	---	0.33	0.05	---	1111	1348	1749	20	10.5
3	T194	1.84	0.64	0.19	0.07	0.04	1057	1153	1290	8	85.2	M199	2.41	---	0.33	0.05	---	1120	1352	1750	20	9.9
4	L380	1.82	0.64	0.19	0.09	0.04	1061	1149	1293	8	94.1	M200	2.42	---	0.33	0.04	---	1108	1352	1705	20	7.8
5	T195	1.78	0.64	0.19	0.10	0.04	1062	1153	1293	8	94.6	M201	2.40	---	0.33	0.04	---	1115	1350	1703	20	7.8
6	L381	1.79	0.64	0.19	0.10	0.04	1059	1147	1292	8	91.3	M202	2.43	---	0.33	0.04	---	1105	1349	1701	20	7.3
7	T197	1.78	0.64	0.19	0.09	0.04	1060	1149	1288	8	94.9	M203	2.37	---	0.33	0.04	---	1101	1348	1702	20	7.0
8	L383	1.79	0.64	0.19	0.09	0.04	1045	1154	1275	8	99.8	M204	2.40	---	0.33	0.04	---	1102	1350	1701	20	7.6
9	T198	1.79	0.64	0.19	0.11	0.04	1039	1150	1271	8	96.8	M205	2.37	---	0.33	0.04	---	1103	1349	1701	20	7.8
10	T199	1.77	0.64	0.19	0.09	0.04	1038	1136	1269	8	91.2	M206	2.40	---	0.33	0.04	---	1101	1350	1700	20	7.1
11	L386	1.79	0.64	0.19	0.10	0.04	1051	1147	1293	8	96.7	M207	2.37	---	0.33	0.04	---	1107	1352	1700	20	7.4
12	T201	1.80	0.64	0.19	0.10	0.04	1051	1149	1290	8	97.1	M208	2.39	---	0.33	0.04	---	1112	1351	1701	20	8.5
13	T202	1.79	0.64	0.19	0.09	0.04	1053	1151	1290	8	96.7	M210	2.43	---	0.33	0.03	---	1101	1350	1700	20	8.4
14	T203	1.79	0.64	0.19	0.10	0.04	1051	1151	1289	8	100.0	M211	2.39	---	0.33	0.04	---	1101	1354	1701	20	8.4
15	L388	1.79	0.64	0.19	0.10	0.04	1051	1149	1288	8	98.1	M209	2.39	---	0.33	0.04	---	1092	1352	1700	20	8.2
16	T204	1.78	0.64	0.19	0.09	0.04	1051	1152	1288	8	99.8	M212	2.39	---	0.33	0.04	---	1101	1348	1700	20	8.0
17	L389	1.82	0.64	0.19	0.10	0.04	1049	1151	1292	8	100.8	M213	2.46	---	0.33	0.04	---	1106	1350	1700	20	8.1
18	T205	1.78	0.64	0.19	0.10	0.04	1050	1150	1294	8	100.3	M214	2.42	---	0.33	0.04	---	1099	1350	1700	20	8.8
19	T206	1.78	0.64	0.19	0.09	0.04	1046	1149	1291	8	99.6	M215	2.46	---	0.33	0.03	---	1102	1350	1700	22.5	8.6
20	L391	1.81	0.64	0.19	0.09	0.04	1054	1152	1288	8	99.8	M216	2.38	---	0.33	0.04	---	1106	1351	1698	20	7.9

TABLE 3-7
 (CRD) COATING RUNS (Y-12 ELEMENTS) (U)

PW Run No.	NbC Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Wt. Avg. gms.	ZrC Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Wt. Avg. gms.
		Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"				Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"		
23	T208	1.78	0.64	0.19	0.09	0.04	1050	1150	1292	8	99.3	M217	2.37	---	0.33	0.04	---	1099	1350	1701	20	8.3
24	T209	1.79	0.64	0.19	0.10	0.04	1052	1150	1289	8	99.2	M218	2.37	---	0.33	0.04	---	1107	1350	1701	20	7.9
25	L393	1.82	0.64	0.19	0.09	0.04	1044	1152	1290	8	97.2	M219	2.40	---	0.33	0.04	---	1105	1350	1699	20	8.0
26	T210	1.78	0.64	0.19	0.10	0.04	1051	1151	1293	8	98.2	M220	2.37	---	0.33	0.04	---	1102	1348	1700	20	8.5
27	T211	1.78	0.64	0.19	0.09	0.04	1050	1152	1290	8	99.1	M221	2.38	---	0.33	0.05	---	1101	1349	1701	20	8.6
28	L394	1.83	0.64	0.19	0.09	0.04	1049	1147	1291	8	97.6	M222	2.38	---	0.33	0.04	---	1107	1348	1700	20	8.6

TABLE 3-8

(CRD) EXPERIMENTAL FUEL ELEMENT REQUIREMENTS AS-COATED (U)

1. Bore Coating Requirements

NbC GEM			ZrC GEM		Total Coating	
Station	Min. Thickness	Max. Thickness	Station	Min. Thickness	Station	Max. Thickness
0	0.5	2.0	0	0.5	0	3.0
10	1.0	2.0	10	1.0	10	3.8
50	1.0	2.0	50	3.5	50	6.0

$$50 \pm 20 \text{ gr Nb} = 56 \pm 23 \text{ gr NbC}$$

$$90 \pm 20 \text{ gr Zr} = 102 \pm 23 \text{ gr ZrC}$$

2. Back Coat and Across Flats

Total Back Coat Thickness	
Station	Min. Thickness
47-48.5	Flash Permitted
48.5-49	Visible
49	1.5
52	2.0
End Face	2.0

Final Across Flats Dimension	
Station	Dimension
46	Reference
47-51.5	Ref. + 0.0003 Max.
49-52	Ref. - 0.0048 Min.
52	Ref. - 0.0008 Min.

3. Air Impedance

0.0935 Minimum As-ZrC Coated

TABLE 3-9

(CRD) EXPERIMENTAL FUEL ELEMENT COATING (U)

Batch 1 - 0.105 Bore AXF
 Run No. 21

	Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"	Time hrs.	Weight Avg. gms
NbC GEM Run L390	1.83	0.64	0.19	0.11	0.04	1035	1128	1179	8	50.2
ZrC GEM Run F444	2.14	---	0.33	0.04	0.02	1078	1198	1320	25	87.8
ZrC HED Run M223	2.46	---	0.33	0.04	---	1107	1350	1699	10	3.8

Batch 2 - PyC Impregnated 0.105 Bore AXF
 Run No. 22

	Ar	HCl	H ₂	Salt	CH ₄	1"	26"	52"	Time hrs.	Weight Avg. gms
NbC GEM Run L392	1.80	0.64	0.19	0.08	0.04	1035	1121	1181	8	42.0
ZrC GEM Run F448	2.17	---	0.33	0.06	0.02	1077	1202	1330	25	88.6

3.12 (CRD) Hardware (U)

(CRD) The hot end support hardware for Pewee-2 consisted of four items which received an NbC diffusion coating. No significant processing problems were encountered.

- a. The pedestals and outer cups, with a 75/25 by weight NbC/graphite composite substrate, were coated at 1850°C for 12 hours for a 2-4 mil coating.
- b. The inner cups of pyrolytic graphite received a 0.7 to 1.7 mil coating in 3 hours at 1960°C.
- c. The graphite sleeves were coated 2 to 3.5 mils thick during two cycles of 6 hours each at 1940°C. The parts were rotated 60°C between the two cycles to insure coating on all surfaces.

(U) A series of hardware, proposed for the R-1 reactor, was also coated for testing in Pewee-2. This series consisted of tip extensions, inner cups, and outer cups. There were no sleeves coated with this series. The coating processes and thicknesses were identical to those used for the standard hardware.

4.0 (U) QUALITY CONTROL (U)

(U) The WNCO Quality Control program in support of Pewee-2 was successfully completed with inspection, testing, data evaluations, and certifications completed on schedule. The non-destructive testing for Pewee-2 was also completed with a minimum of equipment downtime. As a result of consistent systems' performance and the timely engineering review of all measurements, no reported data anomalies were experienced.

4.1 (U) Approval Requests (U)

(U) A total of 78 Approval Requests and Supplements were issued by WNCO to document Pewee-2 inspection, test, and processing procedures. These submittals are listed on the following page.

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<u>Approval Request No.</u>	<u>Supplements</u>	<u>Principle Subject</u>
AR 30000	4	Fuel Element Inspection Plan
AR 30001	-	Element Raw Materials
AR 30002	-	Element Graphitizing and Leaching
AR 30004	-	Tip Stock Destructive Test
AR 30005	-	Transition Stock Raw Material and Process
AR 30006	-	Brazing and Graphitizing
AR 30007	3	Gamma Counting
AR 30009	-	Element Process
AR 30010	4	Transition Stock Inspection Plan
AR 30011	-	Transition Stock Machine Procedure
AR 30012	4	Internal Beta Backscatter
AR 30013	-	Chemical Analyses and Eddy Current
AR 30014	4	Fuel Element Inspection Procedure Update
AR 30015	1	External Beta Backscatter
AR 30016	1	Inspection Coating Weights and Across Flats
AR 30017	1	Inspection of Hot End Hardware
AR 30018	-	Sleeve Coating Procedure
AR 30019	-	Cup Coating Procedure
AR 30020	-	Pedestal Coating Procedure
AR 30021	-	Fuel Element Materials and Process Update
AR 30022	-	Tip Extension Coating Procedure
AR 30024	-	Leach Process Update
AR 30025	3	Element Coating Process Update
AR 30026	1	Pack and Ship Procedure
AR 30027	2	Tip Brazing
AR 30028	2	Element Certification Data Package
AR 30029	-	Support Hardware Coating Procedure
AR 30030	-	Experimental Element Flour Properties
AR 30031	-	Experimental Element Materials
AR 30032	-	Experimental Element Brazing
AR 30033	-	Channel Coating Inspection
AR 30034	-	HHE Experimental Element Processing

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<u>Approval Request No.</u>	<u>Supplements</u>	<u>Principle Subject</u>
AR 30035	-	SMC Experimental Element Processing
AR 30036	-	Post Impregnation Leach
AR 30037	1	MULE Testing
AR 30038	-	Hydrolysis Testing
AR 30039	1	Pyro Coat Process
AR 30040	2	Coating Removal Rework Procedure
AR 30041	-	Poison Wire Test
AR 30042	1	Coating Profile Calculation by MULE
AR 30043	1	Thermal and Flexure Testing
AR 30044	-	Experimental Element Coating

4.2 (U) Inspection/Testing Innovations (U)

(U) Due to changes in element design and advancements in NDT and inspection techniques, many Quality Control innovations were applied for the first time during Pewee-2. Several of the more significant changes are listed below:

4.2.1 (CRD) MULE (U)

(U) Immediately prior to Pewee-2, a Mass/Unit Length Evaluation (MULE) system was received at WNCO from LASL. This system had a ten curie source, and was initially installed and placed in operation to determine incremental corrosion test weight losses.

(U) Following extensive statistical analyses using beta backscatter standards for calibration and Pewee-2 production elements for repeatability studies, the MULE system was applied for the first time at WNCO to determine and report coating profiles. For the first time also, WNCO developed and applied internal coating standards based on chemistry rather than metal foil. The substitution of the MULE system for internal beta backscatter to measure Pewee-2 coating profiles is documented by Variation Request No. 5640 and AR No's. 30037 and 30042.

(CRD) The MULE system was used throughout Pewee-2 to determine incremental weight losses of all corrosion test elements and to determine all coating profiles. Separate computer programs were established for reduction and reporting of Nb and Zr profiles by apportioning coating weights and by referencing counts to calibration curves.

4.2.2 (CRD) Resistivity(PDE) (U)

(CRD) A new, multiplexing PDE system built at UCCND (Y-12) was installed, checked out, calibrated, and placed on line for Pewee-2. For the first time, electrical resistance readings were taken over the full length of every production element before and after every coating operation. These data greatly assisted engineering evaluations of corrosion test element performance, and will contribute to post reactor test evaluations of core elements.

4.2.3 (CRD) Leak Tests (U)

(CRD) Two new leak test systems were fabricated and placed on line for Pewee-2. A new whole body leak test system was applied to shorten test times. A new tip joint leak system was fabricated to obtain the sensitivity needed to determine compliance with the reduced Pewee-2 joint leak specification of 10 cc/min maximum.

(U) The old method required that the whole element be leak tested twice - once with the joint exposed and once with the joint sealed - so as to determine joint leakage by subtraction. The new system isolated the joint within a chamber and measured leakage directly.

4.2.4 (U) Air Impedance (U)

(U) A new air impedance test fixture was introduced for the first time to measure Pewee-2 elements. This fixture required only axial pressure by the Technician to seal the air nozzle against a channel entrance and thereby eliminated much of the data inconsistency and retesting which had previously been experienced with hand-held air probes.

4.2.5 (CRD) Gamma Counters (U)

(CRD) The first of two new, vertical high speed gamma counting systems was placed on line and used throughout Pewee-2 to determine all WNCO and Y-12 matrix element uranium loadings. For the first time, final uranium loadings were determined for delivered elements in the as-leached state. During previous core programs, gamma counts for final loading determinations had been taken following the final coating operation and then corrected for attenuation caused by the coating.

(U) Another innovation at WNCO for Pewee-2 was the operational, setup calibration of the gamma counter against the specific standard for the loading of the element to be tested. Previously this setup had been performed only with standards representing the end points of the loading/calibration curve.

(CRD) Chemistry evaluations for agreement with NDT findings indicate that the reported Pewee-2 element loadings are more accurate than for any previous WNCO core program. Table 4-1 shows the comparison of WNCO NDT versus chemistry values for U, Nb, and Zr from a cross section of Pewee-2 destructive test elements.

4.3 (CRD) Inspection (U)

(U) The inspections and tests performed to provide process control and engineering evaluation data, and to determine compliance with final item drawings and specifications for shipment certification actions are defined by Q.C. Process Plans. The Pewee-2 as-leached, as-Nb coated, and final inspection plans are shown by Tables 4-2 through 4-5 of this report.

(CRD) The number of core candidate elements and support hardware items processed through various Pewee-2 inspection operations was as follows:

<u>Inspection Operation</u>	<u>No. of Pieces Inspected</u>
As-Machined Elements	1,100
As-Leached Elements	1,050
As-Nb Coated Elements	1,015
As-Zr Coated Elements	975
Final Elements	935
Pre-Corrosion Test Inspection	140
Post-Corrosion Test Inspection	144
Outer Cups	182
Pedestals	145
Inner Cups	132
Outer Sleeves	176
Tip Extensions	56

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TABLE 4-1

(CRD) CHEMISTRY VERSUS NDT (U)

<u>Uranium Analysis by Loading Code</u>			
<u>Load Code</u>	<u>Average NDT*</u>	<u>Average Chemistry*</u>	<u>% Difference NDT to Chemistry</u>
243	66.6187	66.8134	-0.29
323	89.0663	89.0625	+0.01
430	119.2790	119.2578	+0.02
521	145.8053	146.7207	-0.62
** 521	146.6343	146.6919	-0.04
573	164.2470	164.3982	-0.09
630	<u>180.5433</u>	<u>179.9309</u>	<u>+0.34</u>
Average	130.3134	130.4107	-0.07

<u>Niobium Analysis by Loading Code</u>			
243	82.3300	81.7369	+0.73
323	90.7867	90.5776	+0.23
430	82.4133	82.0833	+0.40
521	85.3700	84.8360	+0.93
** 521	37.0756	36.7807	+0.80
573	89.4726	90.4431	-1.07
630	<u>90.0593</u>	<u>90.7005</u>	<u>-0.71</u>
Average	79.6439	79.5940	+0.06

<u>Zirconium Analysis by Loading Code</u>			
243	9.1333	9.0503	+0.92
323	8.4667	8.2616	+2.48
430	8.1333	8.2901	-1.89
521	7.5000	7.5497	-0.66
** 521	76.5000	76.6677	-0.22
573	7.5333	7.2690	+3.64
630	<u>7.9667</u>	<u>7.8301</u>	<u>+1.74</u>
Average	17.8904	17.8455	+0.25

* grams per element of constituent
** 939J709 G02 (HHE)

NOTE: Averages obtained per
PDS-30134 requirements.

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TABLE 4-2

(U) AS-LEACHED Q.C. PROCESS PLAN (U)

Operation	Procedure (Reference AR)	QCOO	Inspection Form
(1) Visual & Dimensional Inspection	QIP No. 1001, Rev. 0 (AR 30000-0) SIP No. 300, Rev. 1 SIP No. 301, Rev. 0	N/A	Rev. 3, ALI, PW-2, 11139 OA Form No. 631-5
(2) MULE	QIP No. 517, Rev. 1 (AR 30037)	106, Rev. 0	Per Procedure
(3) Body Leak	SIP No. 203, Rev. 1 (AR 30000-2)	111, Rev. 0	Rev. 3, LTI, PW-2, 11139 OA
(4) Joint Leak	QIP No. 521, Rev. 1 (AR 30000-4)	N/A	Rev. 3, LTI, PW-2, 11139 OA
(5) Incremental Leak	SIP No. 205, Rev. 0 (AR 30000-0)	N/A	Rev. 3, LTI, PW-2, 11139 OA
(6) External Eddy Current	SIP No. 102, Rev. 0, & Supp. No. 1 (AR 30000-0)	N/A	Per Procedure
(7) Internal Eddy Current	SIP No. 103, Rev. 0, & Supp. No. 1 (AR 30000-0)	N/A	Per Procedure
(8) Gamma Count			
(a) Vertical (Prime)	QIP No. 526, Rev. 0 (AR 30012-3)	105, Rev. 1	Per Procedure
(b) Horizontal	QIP No. 27, Rev. 3 (AR 30007-0)	100, Rev. 4	Per Procedure
(9) PDE			
(a) Y-12 (Prime)	QIP No. 525, Rev. 0 (AR 30000-1)	104, Rev. 4	Per Procedure
(b) <u>W</u>	SIP No. 101, Rev. 0 (AR 30000-0)	N/A	Per Procedure
(10) Bore Diameters (Hot End)	QIP No. 552, Rev. 0 (AR 30033-0)	N/A	HEBS, Rev. B (1/22/70)

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TABLE 4-3

(U) AS-NbC COATED Q.C. PROCESS PLAN (U)

Operation	Procedure (Reference AR)	QCOO	Inspection Form NbCl, Rev. 3 (02110)
(1) MULE	QIP No. 517, Rev. 1 (AR 30037-0)	106, Rev. 0	Per Procedure
(2) Bore Diameters (Hot End)	QIP No. 552, Rev. 0 (AR 30033-0)	N/A	HEBS, Rev. B (1/22/70)
(3) External Beta Backscatter	QIP No. 538, Rev. 3 (AR 30015-1)	102, Rev. 1	Per Procedure
(4) Air Impedance	QIP No. 51, Rev. 5 (AR 30014-0)	103, Rev. 2	All, Rev. 2, 11209
(5) PDE			
(a) Y-12 (Prime)	QIP No. 525, Rev. 0 (AR 30000-1)	104, Rev. 4	Per Procedure
(b) <u>W</u>	SIP No. 101, Rev. 0 (AR 30000-0)	N/A	Per Procedure
(6) Across Flats (Engineering Information Only)	Snap Gage/Micrometer (AR N/A)	N/A	Engineering Across Flats Form (10/15/69)
(7) Visual Tip, Element and Coating	SIP No. 301, Rev. 0	N/A	Matrix - Form 631-5 Coating - Form EDSK-333223-A, Rev. 6

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TABLE 4-4
(CRD) AS-FINAL COATED Q.C. PROCESS PLAN (U)

Operation	Procedure (Reference AR)	QCOO	Inspection Form ZrCl ₄ PW-2, 03130, OA
(1) MULE	QIP No. 517, Rev. 1 (AR 30037-0)	106, Rev. 0	Per Procedure
(2) Bore Diameters (Hot End)	QIP No. 552, Rev. 0 (AR 30033-0)	N/A	HEBS, Rev. B (1/22/70)
(3) External Beta Backscatter	QIP No. 533, Rev. 3 (AR 30015-1)	102, Rev. 1	Per Procedure
(4) PDE			
(a) Y-12 (Prime)	QIP No. 525, Rev. 0 (AR 30000-1)	104, Rev. 4	Per Procedure
(b) <u>W</u>	SIP No. 101, Rev. 0 (AR 30000-0)	N/A	Per Procedure
(5) Coat Length	N/A (Scale)	N/A	ZrCl ₄ PW-2, 03130, OA
(6) Visual Tip, Element and Coating	SIP No. 301, Rev. 0	N/A	Matrix - Form 631-5 Coating - Form EDSK-333223-A, Rev. 6

TABLE 4-5

(U) Q.C. FINAL INSPECTION PROCESS PLAN (U)

(1) Dimensional Inspection	QIP No. 1002, Rev. 1 (AR 30016-1)	N/A	FI, PW-2, Rev. 3, 03130, OA AF-2, PW-2, Rev. 3, 02110
(2) Visual Tip, Element, Coating	SIP No. 301, Rev. 0 (AR N/A)	N/A	Matrix - Form 631-5 Coating - Form EDSK-333223-A, Rev. 6
(3) Weigh	N/A (AR 30015-0)	N/A	FI, PW-2, Rev. 3, 03130, OA
(4) Air Impedance	QIP No. 51, Rev. 5 (AR 30014-0)	103, Rev. 2	All, Rev. 2, 11209

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4.4 (U) Variation Requests (U)

(U) A total of 145 Variation Requests (VR's) and Supplements were issued to document discrepancies against Pewee-2 elements, support hardware, and test specimens. The majority of the Engineering Review Board (ERB) meetings to disposition these VR's were held by WNCO Q.C. at WNCO to facilitate the evaluation of visual matrix and coating defects and to assure the timely availability of supporting documentation.

4.5 (U) Corrosion Test (U)

(U) The Pewee-2 fuel elements were corrosion tested* at A.07 (Q.C. test), A.04, or D.01/D.02 conditions. All the Pewee-2 batches were acceptable for core use from a corrosion standpoint. Six (6) of the batches were accepted through VR action because they gave corrosion results that deviated slightly from the corrosion specification, PS 597954. These batches are identified in Table 4-6 which gives the corrosion results of all the Q.C. testing of Pewee-2 elements.

4.5.1 (CRD) A.07 Test (U)

(CRD) The A.07 - 6 x 10 minute Q.C. testing of twenty (20) WANL-AXM matrix elements gave an average total weight loss of 6.1 grams/element and incremental losses of 1.6 grams in the 0-35 inch region (range 0.6 to 2.6 grams) and 4.0 grams in the 35-50 inch region (range 2.5 to 6.9 grams). Similar testing of five (5) Y-12 AXF matrix elements gave total weight losses of 4.8 grams/element and incremental losses of 1.8 grams in the 0-35 inch region (range 1.3 to 2.0 grams) and 2.7 grams in the 35-50 inch region (range 2.0 to 3.0 grams).

(CRD) The wide range in the hot end losses reflect defect corrosion (corrosion through coating cracks) which occurred in many of the elements in the 30 to 45 inch region. The extent of defect corrosion can be determined by comparing the actual weight losses with those that would be expected from diffusion corrosion alone. Considering the test temperatures, the

* A description of all corrosion test conditions used for Pewee-2 elements may be found in DRM 51346, Rev. A, Fuel Element Corrosion Test Designations.

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coating thickness and test times, the diffusion component of the weight loss would typically be 2.4 grams over the 35-50 inch region of the Pewee-2 elements. The defect corrosion became more pronounced during extended time testing. For seven (7) elements tested for times between 60 and 116 minutes the average 35-50 weight loss rate increased from 0.05 grams/minute to 0.15 grams/minute during the test period beyond the first sixty minutes. (CRD) Midband weight losses in the Pewee-2 elements were generally low, but about 50 percent of the elements did have some additional losses due to a corrosion effect that was unique to the outer webs, particularly those at the corner bores. This corrosion occurred mainly as an attack of the pyrocarbon shells and the matrix surrounding the fuel beads. In a few of the elements the corrosion was extensive enough to cause pinholing. A correlation was found between the occurrence of this pinholing and the electrical resistance parameter (coating cracks) of the bore coating.

(CRD) The heavy hot end elements were corrosion tested at revised conditions as the original elements broke upon startup when tested at A.07 conditions. The revised conditions, termed A.08 (reduced power, flow, and external He pressure), gave the same channel wall temperatures as the A.07 test. Weight losses (6×10) of the elements were low, and hot end values were similar to those expected from carbon diffusion. The element without PyC had a 3.5 gram total weight loss and the one with PyC, 2.9 grams.

(CRD) One element from each coating batch was also tested at A.07 conditions after being hydrolyzed for 5 days at 95°C and 100% relative humidity. All the Pewee-2 elements were sensitive to some degree of hydrolysis and only three (3) tested for an A.07 6×10 minute period. All elements showed some corrosion pocket formation in the 15-40 inch region, with the maximum number of pockets occurring in the 20-30 inch region. The number of corrosion pockets and pinholes were highly related to pre-hydrolysis coating cracks as determined by electrical resistance studies.

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4.5.2 (CRD) A.04 Test (U)

(CRD) Four (4) Pewee-2 elements tested at A.04 30 + 30 conditions had weight losses of 3.4 grams/element. The incremental losses were 1.0 gram in the 0-35 inch region and 2.4 grams in the 35-50 inch region. This hot end loss is equivalent to the diffusion corrosion component alone. During extended time testing at these conditions, some defect corrosion occurred and the elements experienced an increase in hot end corrosion rates similar to the increase observed in the A.07 tests.

4.5.3 (CRD) D.01/D.03 Test (U)

(CRD) Twenty (20) Pewee-2 elements were corrosion tested at D.01/D.02 conditions. Most of the elements did not achieve the target test time of 12 x 10 minutes primarily due to breaks occurring at the hot end chuck; some of the elements (D.02 test) also pinholed due to severe defect corrosion. Defect corrosion with the D.01/D.02 tests peaked at about Station 44, the same position as with A.07 testing, even though the A.07 temperatures were considerably higher at this position. Five (5) D.01/D.02 elements developed pinholes due to outer web corrosion.

4.5.4 (U) Poison Wire Insertion (U)

(U) In order to establish that insertion of poison wires into the bores would not cause damage to reactor elements, all of the corrosion tested elements, except the hydrolyzed elements, had LASL type poison wires inserted into the bores prior to testing. All bores except numbers 8 and 9 were probed; these two bores were utilized as "control bores" when the elements were axially sliced for post test visual examination through channels 8, 9, 10, 11, 12.

(U) The poison wire testing established that coating nodules did not prevent poison wire insertion into at least 9 bores, per the LASL requirement, and also that poison wire insertion did not cause extra bore corrosion.

TABLE 4-6

(CRD) SUMMARY OF Q.C. CORROSION TEST RESULTS (U)

Batch	Coating Batch	Element	Matrix	Desig.	Test Time	Corrected Test ΔW Grams	Pinholes		Incremental ΔW	
							0-35	35-48	0-35	35-50
1 ⁽¹⁾	T193/M197	473-102314	AXM	A.07	6 x 10	9.9	---	---	2.4	6.9
2 ⁽¹⁾	L379/M198	473-102361	AXM	A.07	3 x 10 + 3 x 10	6.2	---	---	1.6	4.2
3	T194/M199	473-102354	AXM	A.07	10 + 4.2 + 15.8 + 3 x 10	5.2	---	---	1.3	3.2
4 ⁽¹⁾	L380/M200	391-102493	AXM	A.07	6 x 10	7.8	7	---	2.6	4.9
5	T195/M201	521-102080	AXM	A.07	6 x 10	6.8	---	---	1.3	5.0
6	L381/M202	521-102139	AXM	A.07	6 x 10	6.7	---	---	1.8	4.4
7	T197/M203	521-102134	AXM	A.07	3 x 10 + 3 x 10	6.3	---	---	2.6	3.4
8	L383/M204	391-102499	AXM	A.07	6 x 10	3.6	---	---	0.6	2.5
9 ⁽¹⁾	T198/M205	391-102543	AXM	A.07	6 x 10	6.4	---	---	1.6	4.4
10	T199/M206	521-102084	AXM	A.07	5 x 10 + 10	4.7	---	---	1.4	2.8
11	L386/M207	323-102682	AXM	A.07	5 x 10 + 3 + 7	5.2	---	---	1.4	3.4
12	T201/M208	323-102723	AXM	A.07	5 + 15 + 2 x 10 + 9 + 11	6.2	---	---	1.3	4.3
13	T202/M210	323-102702	AXM	A.07	6 x 10	5.9	---	---	1.7	3.9
14	T203/M211	323-102724	AXM	A.07	6 x 10	8.5	---	---	1.9	6.2
15	L388/M209	473-102284	AXM	A.07	5 x 10 + 10	4.0	---	---	1.1	2.7
16	T204/M212	521-102751	AXM	A.07	6 x 10	5.1	---	---	1.1	3.6
17	L389/M213	521-102154	AXM	A.07	6 x 10	4.8	---	---	1.4	3.1
18	T205/M214	521-102184	AXM	A.07	6 x 10	6.3	---	---	2.2	3.8
19 ⁽²⁾	L390/F444/M223	521-102987	AXF	A.08	6 x 10	3.5	---	---	0.8	2.2
20	T206/M215	521-102817	AXM	A.07	6 x 10	6.7	---	---	1.7	4.7
21	L391/M216	521-102794	AXM	A.07	6 x 10	4.8	---	---	1.0	3.5
22 ⁽²⁾	PyC/L392/F448	521-103009	AXF	A.08	6 x 10	2.9	---	---	0.5	1.8
23-Y1	T208/M217	630-101520	AXF	A.07	6 x 10	4.3	---	---	1.3	2.8
24-Y2	T209/M218	630-101804	AXF	A.07	6 x 10	5.6	---	---	2.1	3.0
25-Y3	L393/M219	630-101554	AXF	A.07	6 x 10	4.9	---	---	1.6	3.1
26-Y4 ⁽¹⁾	T210/M220	630-101824	AXF	A.07	6 x 10	4.2	2	---	2.0	2.0
27-Y5 ⁽¹⁾	T211/M221	630-101836	AXF	A.07	6 x 10	4.9	4	---	1.9	2.7

- (1) Batches accepted by VR action: T193/M197 - weight loss above specification limits.
 L380/M200, T210/M220, T211/M221 - pinholes.
 L379/M198, T198/M205 - difficulty in poison wire insertion.
- (2) Heavy hot end batches.

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4.6 (U) Shipment Certifications (U)

(U) Completely new Q.C. computer certification data packages were designed and programmed for Pewee-2. For the first time an attribute computer report was generated for all element visual and dimensional characteristics. This report also included a record of all Variation Request actions. The coordination and transmittal of computer data packages and data cards between W and LASL was established directly between WNCO Q.C. and cognizant LASL activities. A total of 131 Shipping Releases (QCSR's) were issued for the following Pewee-2 items:

<u>Item Required by Work Order</u>	<u>No. of W. O. Items Certified for Shipment</u>
Fuel Elements	751
Test Specimens	645
TDL Samples	52
Braze Qual.	114
Tip Extensions	47
Pedestals	75
Outer Sleeves	83
Outer Cups	117
Inner Cups	<u>64</u>
Total	1,948

TITLE	
	Summary Fabrication Report for Pewee-2 Fueled Elements	
DOCUMENT NO.		DATE
WANL-TME-2788		May 28, 1971
ABSTRACT		
<p>The WNCO production campaign for Fuel, Test Components, and Support Hardware for the PW-2 Reactor is reviewed. New process innovations and non-destructive test techniques are identified and reviewed. Process yields and conformance to specifications for many of the process steps are analyzed and tabulated.</p>		
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