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April 16, 1968

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Subcontract NP-1

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IRP	U	5-11-82
DETERMINATION		
Class: U		

A PRELIMINARY SUMMARY OF THE
PEWEE I MANUFACTURING CAMPAIGN
(Title Unclassified)

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INFORMATION CATEGORY
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Authorized Classifier Date

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INTRODUCTION

This report was prepared as a brief summary of the combined efforts of Westinghouse Astronuclear Core Operations (WNCO) and Westinghouse Experimental Fuel Facility (WEFF) for fabrication of fuel elements and non-fueled reactor support hardware for the Pewee I Reactor. A discussion of these efforts regarding production scheduling, processing, and fuel element quality with respect to problems and solutions in each respective area is presented.

The report is considered to be a preliminary summary available for review while more detailed investigations and examinations are prepared for incorporation into the publication of the final Pewee I Fabrication Report (milestone event scheduled for October, 1968).

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SUMMARY

The Pewee I core parts supplied by WINCO and WEFf consist of a combination of variables such as higher fuel loadings, larger flow channels, impregnated and additive element matrices, composite tips, and new and/or different protective coating processes.

The fabrication of the various parts was essentially normal with respect to previous successful efforts except for noticeable tooling wear associated with machining the harder composite materials, minor process control difficulties inherent in the new coating processes, and some resultant fuel element coating characteristics which required reworking and/or variation request actions for acceptance to the core.

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I. PRODUCTION PERIODS, REQUIREMENTS, AND YIELDS

Pewee I production began at WNCO on December 7, 1967, and the final shipment of all fuel elements from WNCO occurred on April 15, 1968. GEM coating at WEPF began on February 27, 1968, and was completed on March 26, 1968.

WNCO delivered 220 core, spare, sample, and corrosion test fuel elements which was 59 elements over the required quantity. Forty (40) additional core candidates were shipped to Y-12 in the as-impregnated condition for further processing. A summary is shown in Table I. For a detailed classification by code and type of required and supplied core quantities, see Table II. The WNCO fuel element production effort expended in fulfilling core requirements and the associated yields for processing operations is summarized in Table III.

WNCO also provided (or will provide) an additional 210 fuel elements for other engineering tests and evaluations as defined in Table IV.

The production of unfueled reactor structural hardware and fueled elements was a parallel effort. A summary of the structural hardware coated at WNCO and delivered for each style is shown in Table V.

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II. PROCESSING

A. Extrusion

Pewee I elements extruded at WNCO consisted of a DCI with 85 parts graphite flour (Great Lakes Carbon Co., P.O. 89772, Lot 2) to 15 parts carbon black, General Atomic fuel beads, and 27 percent varcum catalyzed with maleic anhydride.

The extrusion run was normal and in accord with previous experiences at a pressure of 95 ± 10 tons and a rate of 100 ± 10 in/min. Variations to these parameters and a production summary is given in Table VI. A problem with cracking was observed during the extrusion of the first two batches. At that time, the press was re-aligned, the varcum delivery system was thoroughly wetted, and the plenum was uniformly heated. No further abnormalities in cracking were noted during the remainder of the extrusion run.

All extrusions were monitored by infra-red techniques for temperature variations along the element length. Preliminary data indicated that the extrudate temperature changed from batch to batch and within a given element. These data are presently being correlated with subsequent processing and inspection data.

Twenty-four hour engineering coverage was provided during the Pewee I extrusion run.

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Pewee I tip stock was fabricated at WNCO with DCI consisting of 85 parts graphite flour (Great Lakes Carbon Co., P.O. 89772, Lot 2) to 15 parts carbon black, and 27 percent varcum catalyzed with maleic anhydride. Previous (NRX-A6) production experience was used to establish extrusion parameters and binder content. The major innovation in tipping for Pewee I was the incorporation of a composite tip. The tip configuration consisted of a 0.4 inch 75% NbC/25% C composite resistance brazed to a 0.6 inch section of WNCO extruded tip stock. This composite tip was in turn induction-brazed to an element with the 75%/25% portion positioned at the extreme end. The tips, ready for assembly to the fueled elements, were supplied by WANL.

B. Machining

The Pewee I elements were machined according to the same manufacturing procedures used for NRX-A6 and XE-2 fuel elements. A total of 470 carbide-tipped elements, plus 80 non-fuel elements, were milled without any serious degradation in the diamond cutting tools. This performance matched the best of any previous diamond milling for high loaded graphite-tipped elements.

The reaming of carbide versus graphite-tipped elements was similar in regard to tool wear. However, twice as much tooling wear was noticed for reaming the 2 $\frac{1}{2}$ % additive elements.

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The manual tapering tool used for tapering the hot end of graphite-tipped elements was unsatisfactory for carbide-tipped elements due to the required increased taper depth and material hardness. The operation was performed on a new undercut machine (Winslow) with successful control of allowable tolerances and few in-process adjustment demands.

C. Leaching

The leaching cycle employed was the same as that used previously, 3 hours at 1700°C. Leaching operations during Pewee I were trouble-free and performed according to predicted expectations based on previous experience. Mechanical brush cleaning of the bores replaced the manual techniques used previously.

D. NbC GED Coating

The GED ("G"-End diffusion) process selected for the NbC coating of Pewee I elements utilized a higher hydrogen/salt ratio than that used previously (2.25/1 versus 1/1). The coating temperatures were 1370°C, 1530°C, and 1780°C for the cold end (serial-numbered end), middle, and hot end of the elements, respectively. Other than a lowering of salt concentration to effect the desired hydrogen/salt ratio, no changes in flows or gas composition were made. The primary purpose of this change was to increase deposition rate without compromising corrosion performance. Thus, Pewee I elements had 3 mil thick hot-end coatings deposited in the same length of time (14 hours) that was used previously to apply 2 mil thick coatings.

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Two processing problems were associated with the GED coatings. First, difficulty in control of weight gain and thickness profile was experienced. (See Table VII.) Second, three runs exhibited abnormally thick cold-end coatings (up to 1.6 mils). Reasons for these conditions were not immediately apparent, but studies to understand the problems are presently being conducted.

E. NbC GEM Coating

GEM ("G"-End Methane) coating at WEFF was limited to production in one furnace ("B") due to difficulties experienced in attaining a linear temperature profile in the second furnace ("G"). This fact was discovered after the first "G" furnace run (G-99).

A slightly low weight gain on Run B-219 warranted an increase in temperature (10° above nominal) for Run B-220. Run B-220 elements had a slightly high (98.5 gm/FE) weight gain which was corrected in the remaining production runs by lowering the temperature to only 5°C above nominal.

F. Molybdenum Coating

The molybdenum overcoating process was modified (increased total gas flow 24%) to maintain the same coating gas velocity for the high void Pewee I elements as was utilized for the previous low void elements.

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Coating profiles, as determined with resistance measurements, were similar to XE-2 and A-6 profiles and weight gains were equivalent. Table VIII is the production summary including weight deposition and retention values. It should be noted that the standard matrices (G05K) retained less molybdenum than the additive elements (G07K), which in turn retained less than the impregnated (G06K) elements.

III. QUALITY

A. Hydrogen Corrosion Test

The WNC0 GED production effort (10 NbC Runs) passed corrosion tests and were 100% acceptable as core candidates.

Of the WEFF GEM production effort (8 NbC Runs), six (6) runs passed corrosion tests, of which only five (5) were utilized for core use. The sixth run (B-222) passed the A6.04 test but exhibited corrosion holes at the hot-end during the PW 1.02 corrosion test, and was therefore not considered as a core candidate. The B-221 elements were not accepted to the core because they failed the corrosion test in the mid-band region and the coating was non-adherent as compared to other GEM runs. The eighth production run (G-99) was not accepted as core quality due to its high weight gain (147 gm/element).

B. Fuel Element Permeability

A maximum acceptance level of 170 cc/min leak rate of as-leached elements yielded 78% accepts from WNC0 extrusions (525 mg U/cc) and

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95% accepts from Y-12 extruded elements (477 and 269 mg U/cc). (See Table X.) (It has been previously experienced that leak rate increases with fuel loading.) Those elements above the 170 cc/min level were not processed as core candidates.

C. Cold End Bore Size

The cold end of 67 GEM and 15 GED elements required reworking with a hand reamer to remove coating high spots in the bores. The hand reaming successfully relieved the bores to the requirements of the drawing.

D. Joint Dimensional Variations

During the latter stages of Pewee I processing, Y-12 observed a swelling of their additive matrix elements in the area of the transition tip - fueled element joint at 1" from the hot end. In order to determine if a similar problem existed on WNCO and WEFF coated elements, across flats dimensions were taken on all elements at $\frac{1}{2}$ " intervals in the affected zone. These data shown in Table XI indicate that swelling was not observed in elements processed at WNCO and WEFF. These data also indicate a slight decrease in across flats dimension when proceeding from the 48" point to the hot end (52" point).

E. Hot End Taper

The GED element hot ends were consistently within a taper depth dimension of $0.0033 \begin{smallmatrix} +0.0020 \\ -0.0007 \end{smallmatrix}$ inch after NbC coating. One hundred percent

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of the GEM coated elements required rework to fall within this range.

Rework was performed using the Winslow diamond undercut machine.

F. Variation Request Submittals

There were several fuel element characteristics found during quality inspections which required core acceptance by variation request actions. Primarily, the delinquent characteristics centered around GEM and GED NbC coatings in regards to thickness profiles in hot end (thick) and mid-band (thin) areas, respectively. Justification for core acceptance was based on adequate protective coatings as evidenced by excellent corrosion test results. See Table XII for a summary of variation request submittals and dispositions.

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TABLE I
PW-1 ELEMENTS

Elements Delivered	Required	Actual
Core Plus Spares - Shipped - GED	48	111
Core Plus Spares - Shipped - GEM	40	33
Y-12 Interchange (Impreg.)	40	40
LASL Samples	9	9
MULE Samples	4	4
Spec. Samples	12	12
Corrosion Test	54	51
	<u>207</u>	<u>260</u>

TABLE II
PW-1 CORE ELEMENTS

WNCO Core Requirements						WNCO As-Shipped							
Code	Type *	W.O. Qty.	Spares	Total Ship	Over/ Under	Type NbC	Geom.	Part No.	W.O. Qty.	Spares	Total	Shipped	Over/ Under
525	I	20	0	24	+ 4	GED	08 ¹¹⁰	G06K	10	0	10	18	+ 8
						GEM	08 ⁰	G21K	10	0	10	6	- 4
525	S	22	5	54	+27	GED	08 ⁰	G05K	11	5	16	47	+31
						GEM	13 ¹²	G25K	11	0	11	7	- 4
477	A	20	4	30	+ 6	GED	08	G04K	10	4	14	24	+10
						GEM	13	G24K	10	0	10	6	- 4
269	A	14	3	36	+19	GED	08	G07K	7	1	8	22	+14
						GEM	08	G22K	7	2	9	14	+ 5

* I = Impregnated ; S = Standard; A = Additive

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TABLE III

PEWEE I EFFORT AND YIELDS

Operation	Total	Accept to Core	%
Extrude through Graphitizing	315*	315*	100
First Machine and First Inspection	470**	448	95.4
Leach and Leach Inspections	448	393	87.7
GED Coating			
NbC Coat	135	127	94.0
X Coat	127	123	96.7
Final Inspect and Candidates	123	111	91.0
GEM Coating			
NbC Coat	78	48	61.5
Final Inspect and Candidates	48	33	68.8

TABLE IV

ENGINEERING TEST & EVALUATION ELEMENTS

Destination	Required	Delivered
<u>Delivered</u>		
Materials and Process Development	32	32
Materials Testing Coating Stress Analysis	35	31
Materials Physical Property Testing	15	15
To EML Physical Property Testing	2	2
Fuel Development - Coating Evaluation (G-99)	14	14
	<u>98</u>	<u>94</u>
<u>Additional Elements Requested</u>		
Materials Development Coating Stress Analysis	4	
TFL Corrosion Rig - Development	1	
EML - Physical Property Testing	64	
Materials Development-Extended Tip Development	12	
Materials Physical Property Testing	5	
WNCO Coating Development	8	
WNCO Tip Braze Preproduction Development	4	
WANL - Pool for Future Use	18	
	<u>116</u>	

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*Does not include first 10 elements in the first two extrusion batches.

**Includes 155 elements from Y-12.

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TABLE V

PEWEE I STRUCTURAL HARDWARE

Style	P/N	Work Order Quantity	Quantity Shipped
Pedestal	929F015 G01A	42	56
Outer Sleeve	981D375 H02	43	78
Outer Cup	981D371 H01	37	41
Outer Cup (Long)	981D371 H02A	6	10
Tapered Washer	981D368 H01	42	72
Pyro Cup	981D391 H02B	41	48
Pyro Cup (Long)	981D391 H03B	6	8

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TABLE VI

PEWEE 1 EXTRUSION RUN

	Extrusion Pressure Tons		Extrusion Rate in./min.	
	Average	Range	Average	Range
PEWEE 1	93	85-105	101	93-124*
PEWEE 1 Tailings	105	95-120	102	93-109
* One batch extruded at 124 in./min. The next highest rate was 109 in./min.				

Type of Element	No. of Elements Extruded at 95 ± 10 Tons and 100 ± 10 in./min.	No. of Elements Extruded at Pressure Higher than 95 ± 10 Tons	No. of Elements Extruded at Rate Higher Than 100 ± 10 in./min.
Batch	256	---	7
Tailing **	43	19	---

** Tailing elements were not extruded to the controlled pressure and rate.

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TABLE VII

PEWEE I NbC (GED) PRODUCTION RUNS

Run Number	Element Style/Load	Avg. Δ W/Run(g)	Range (Δ W/Element)
M-136	G05/525	66.9	66.0/68.0
C-396	G05/525	67.5	66.1/68.8
L-313	G06/525	68.4	66.6/69.8
M-137	G07/269	72.8	71.5/73.8
C-397	G07/269	74.1	72.2/75.9
L-314	G05/525	63.0	61.7/64.1
F-387	G05/525	63.7	62.5/64.7
C-398	G05/525	78.5	76.8/79.9
M-138	G04/477	78.0	77.0/79.8
M-139	G04/477	68.5	67.4/69.7

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TABLE VIII

PEWEE 1 X-COAT PRODUCTION RUNS

X Run No.	NbC Run No.	F/E Type	No. of F/E	Avg. Wt. Dep.	Avg. Wt. B/D	Avg. Wt. Ret.
AA-174	M-136	G05K (S)	17	4.97	.88	4.09
	C-396	G05K (S)	18	5.07	.99	4.08
AA-175	M-137	G07K (A)	17	4.92	1.11	3.81
	L-313	G06K (I)	16	5.01	.45	4.56
AA-177	L-314	G05K (S)	18	5.05	1.20	3.85
	C-397	G07K (A)	16	4.93	.42	4.51
AA-178	C-398	G06K (I)	17	4.96	.55	4.41
	F-387	G05K (S)	18	5.15	.80	4.35
AA-179	M-138	G04K (A)	17	5.04	.76	4.28
	M-139	G04K (A)	17	5.35	1.15	4.20

S = Standard; I = Impregnated; A = Additive

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TABLE IX

CORROSION TEST SUMMARY

Matrix	NbC Run	"X" Run	Corrosion Test Results
GED:			
525S 08	C-396	AA-174	Accept
525S 08	M-136		Accept
525I 08	L-313	AA-175	Accept
269A 08	M-137		Accept
525S 08	L-314	AA-177	Accept
269A 08	C-397		Accept
525S 08	F-387	AA-178	Accept
525I 08	C-398		Accept
477A 08	M-138	AA-179	Accept
477A 08	M-139		Accept
GEM:			
525I 08	B-218	-	Accept
525I 08	G-99	-	Abort
269A 08	B-219	-	Accept
269A 08	B-220	-	Accept
477A 13	B-221	-	Reject
525S 13	B-222	-	Reject*
477A 13	B-223	-	Accept
525S 13	B-224	-	Accept

* Passed A6.04 corrosion test
but did not perform well in
Pl.02 corrosion test

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TABLE X

PEWEE I ELEMENT PERMEABILITY

Supplier	Fuel Element Loading	Ranges of Leak Rate (cc/min.) (As Leached)								Total Fuel Elements Evaluated
		0 - 99	%	100-169	%	170-199	%	200 - & over	%	
WNCO	525	112	36	131	42	28	9	39	13	310
Y-12	477	34	44	43	56	0		0		77
Y-12	269	59	81	7	10	1	1	6	8	73

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TABLE XI

PEWEE I JOINT DIMENSIONAL VARIATIONS

Across Flats Dimensions (In.)

Distance from Hot End (In.)	Avg.	GED Low	High	Avg.	GEM Low	High
1	0.7522	0.7512	0.7529	0.7523	0.7512	0.7530
1 1/2	0.7524	0.7514	0.7530	0.7526	0.7515	0.7533
2	0.7524	0.7514	0.7536	0.7526	0.7517	0.7534
2 1/2	0.7526	0.7518	0.7534	0.7526	0.7519	0.7534
3	0.7527	0.7518	0.7534	0.7528	0.7521	0.7534
3 1/2	0.7528	0.7519	0.7534	0.7529	0.7521	0.7534
4	0.7528	0.7519	0.7534	0.7529	0.7521	0.7535

TABLE XII

PEWEE I VARIATION REQUEST SUMMARY

Characteristic Requiring VR Action	Total VR's Submitted	VR's Accepted	VR's Rejected
Internal Profile (NbC)	160	160	0
Internal Deposited Weight (Nb)	47	47	0
Matrix Content (Nb)	34	34	0
Hot End Bore Size	24	24	0
Across Flats Dimensions	26	22	4
External Profile (NbC)	21	21	0
External Deposited Weight (Nb)	19	19	0
End/Side Coat Grade (Chips)	20	16	4

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