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Subcontract NP-1

WANL-TME-2708

July 1, 1970

Westinghouse Astronuclear Laboratory

FINAL REPORT

TEST SPECIFICATIONS 3012 AND 3017

PEWEE 2 DUPLEX COATING DEVELOPMENT (U)

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Westinghouse Astronuclear Laboratory

FINAL REPORT
TEST SPECIFICATIONS 3012 AND 3017
PEWEE 2 DUPLEX COATING DEVELOPMENT (U)

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SPECIAL REVIEW FINAL DETERMINATION	Reviewers	Class.	Date
	<u>TR U</u>	<u>4-20-82</u>	
Class: <u>U</u>			

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(U) ABSTRACT

This report covers the work done at WNCO to develop a coating for use in the Pewee 2 reactor. Information is presented on refining the NbC methane coating process and developing both methane and diffusion coating processes for ZrC. Corrosion test performance of coated elements is discussed and the development of the Pewee 2 coating process is presented.

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1.0 (CRD) INTRODUCTION (U)

(CRD) WFDD-TS-3012 was initiated to study ZrC HED* overcoating of NbC GEM coated elements and WFDD-TS-3017 was initiated to study the development of ZrC GEM overcoating of NbC GEM coated elements. While investigating each of the ZrC coating processes separately, there was continued development of the NbC GEM coating process to improve its characteristics as a base for ZrC overcoating. The work on these programs led to the selection of an improved NbC GEM basecoat and a ZrC HED overcoat for use in the production of Pewee 2 fuel elements.

(CRD) The NbC GEM basecoat improvements were the result of an improved structure and an optimized coating profile. The structure is the "LASL-type" that was first discussed in WANL-TME-1887⁽¹⁾ and was responsible for the superior mid-band performance of the LASL Phase IV-B fuel elements. The development of the NbC GEM coating structure at WNCO was discussed in WANL-TME-1939⁽²⁾. This report gave some of the history of NbC GEM coating and related changes in process parameters to coating structures. Improved profiles were dictated by the post test evaluation of the WEFF-supplied NbC GEM coated elements in Pewee 1 and by results obtained in the more severe Pewee 2 development tests. The Pewee 1 fuel evaluation report, WANL-TME-1937⁽³⁾, related the high 10-15 inch bore loss to the thin NbC GEM bore coatings at those stations and also showed that the severe pinholing at 15 to 20 inches varied with the coating thicknesses at those stations. The post-operational data and electrical corrosion test data showed that the corrosion occurred in areas where thin coatings were damaged as a result of hydrolysis

* (CRD) Coating processes for the NERVA fuel element are described by the following: HED, GED, HEM, or GEM. HE and GE refer to the end of the element as described on the fuel element drawing. The H end is hot in service and the G end is that through which the propellant enters. In coating, the H or G indicates that the coating gases enter that end of the element first and flow toward the other end; D indicates a diffusion coating process and M a methane coating process.

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expanded fuel beads at the coating-graphite interface and that thicknesses exceeding 1.2 mils were necessary to minimize this damage. Hot end bore weight losses of NbC GEM coated Pewee 1 fuel elements were found to decrease with increasing station 40-45 bore coating thicknesses. A similar trend was indicated by evaluating electrical corrosion test data during Pewee 2 development. Therefore, an effort was made to maximize this thickness while retaining an adequate mid-band coating distribution and keeping within the coating weight limitations imposed by the designed neutronics of the reactor.

(CRD) The initial WANL effort on ZrC overcoating was pursued in a single element coating furnace with the goal of providing several experimental elements for the Pewee 2 reactor. This work was reported in WANL-TME-1865⁽⁴⁾ with the conclusion that NbC-coated elements can be successfully ZrC overcoated at the hot end by either a HED or HEM process without degradation of the mid-band and that ZrC overcoating improves the hot end behavior of the fuel element. Similar coating experiments performed on a larger scale at LASL provided elements for highly successful corrosion tests and for inclusion as experiments in the Pewee 1 core. This resulted in an expansion of the WANL program and a re-definition of the coating requirements for the Pewee 2 core from NbC GEM/NbC GED to a ZrC overcoated, NbC GEM basecoat.

(CRD) Data from LASL showed that minor impurities in the coating stream gave an impure ZrC coating within the temperature range (1200° to 1500°C) normally used in GED overcoating. The impurity problem could be overcome without extensive and expensive purification of the coating gases if the temperature of the pre-heat section of the furnace was high enough to remove these impurities as it is in the HED process. GED runs made at WEFF under WFDD-TS-3013 showed that impurities were present and that the GED process deposited a thin coating of ZrN. With the HED process no detectable impurity was found in the element coating, and all subsequent runs were made using the HED process. Data developed under WFDD-TS-3013 was incorporated into WFDD-TS-3012 for development of ZrC HED overcoating at WNCO.

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(CRD) In general, the "best" performing elements in Pewee 1 were the Y-12 NbC GEM coated elements and the LASL ZrC GEM/ZrC GED coated elements. Because of these results and the encouraging results from the electrical corrosion tests of NbC GEM/ZrC HEM coated Phase ID_c elements and the active consideration given to high expansion matrices, WNCO was directed by the SNPO Fuel Committee to develop a ZrC GEM overcoating process (WFDD-TS-3017) and to pursue the development of ZrC HED overcoating and ZrC GEM overcoating concurrently. Copies of WFDD-TS-3012 and WFDD-TS-3017 appear in Appendix A.

2.0 (CRD)NbC GEM COATING DEVELOPMENT (U)

2.1 (CRD)PROCESS DEVELOPMENT (U)

(CRD) The initial NbC GEM coating development runs were made in C furnace using Phase IV-B chemistry. The remaining runs made in C furnace and the runs in L furnace were made with LASL chemistry and a WNCO modification of the LASL chemistry, respectively. These chemistries are compared below:

Chemistry	Nominal Gas Flow, LPME				
	AR	HCl	H ₂	Salt	CH ₄
Phase IV-B	4.50	0.75	0.18	0.09	0.06
LASL	1.77	0.56	0.19	0.08	0.04
WNCO	1.79	0.64	0.19	0.10	0.04

The Phase IV-B chemistry gave coatings with an equiaxed grain structure. The LASL chemistry gave coatings with a very fine-grained dense layer of NbC at the coating-graphite interface and a columnar structure extending from the initial layer. The dense layer prevented some of the coating cracks from reaching the matrix and was responsible for the better mid-band performance of the LASL elements. Photomicrographs of each of the coating types are shown in Figure 2-1.

(CRD) By assuming a constant deposition rate for a fixed set of input parameters, the NbC GEM coating development runs can be broken down into the nine basic types shown in Tables 2-1 and 2-2. During this development period, coating temperature profiles and run times were continually adjusted to improve the profile based on feedback of data from corrosion tests of development elements. This helped to establish the minimum NbC coating thickness for Pewee 2 elements. This thickness and the coating weight range divided by the run time to put everything on a mils/hour and grams/hour basis is shown at the bottom of Table 2-2. A tabulation of coating data for each run is given in Appendix B, Table 1.

(U) A scan of Table 2-2 shows that the Phase IV-B and the LASL Type II coatings would not meet the Pewee 2 requirements for either weight or thickness at any station. The Types I and IIIa coatings would not meet the Pewee 2 requirements for thickness at any station. The Types IV and V coatings would fail the hot end thickness requirements and the Type VI coating would fail the weight and cold end thickness requirements. The Type IIIb coating profile is satisfactory, but its weight exceeds the maximum allowable Pewee 2 NbC coating weight. The Type VII coating is the only type shown that would consistently meet the Pewee 2 requirements as shown on the applicable revision of WANL drawing number 939J023. However, it was the changes made from Types I through VI that led to coating Type VII and established the Pewee 2 profile.

(CRD) As mentioned earlier, the change from Phase IV-B to LASL chemistry was made to change the coating structure to one that gave improved mid-band performance. In adapting LASL parameters to WNCO furnaces, the temperature profiles had to be adjusted to avoid the severe drop in thickness that LASL desired in their GEM coating for overcoating by the NbC GED process. The early efforts made to duplicate the LASL structure are represented by coating that dropped off at the hot end. The mid-band and hot end temperatures were reduced slightly for the Type II coating and gave a good, but light, profile. These temperatures were increased again for the Type IIIa coating, but it was found that the hot end thickness could not be increased by temperature adjustments alone. At this time, NbC GEM coating development was moved from C to L furnace and a new series of development runs was initiated.

(CRD) The hydrogen chloride concentration was increased in the L furnace runs in an attempt to inhibit deposition at the cold end of the element and have a stream richer in niobium species for coating the hot end of the element. This change gave a very desirable structure, the dense inner layer of coating was retained, and a narrow columnar structure was developed nearer the cold end of the element (Type IIIb). Right after the change in furnaces and the change in chemistry, thicker coatings were requested for the cold end of the element. At the high deposition rates that were used, the increased deposition at the

cold end of the element depleted the methane and it was not available for coating at the hot end. Attempts to compensate for the drop in hot end thickness by increasing the deposition temperature were not successful (Types IV and V). Therefore, temperatures were dropped and several runs made to establish the shape of the profile (Types VI and VII). Once this was established, coating run times were adjusted to give the proper coating weight equivalent to 75 ± 15 grams of niobium.

(CRD) The process changes produced corresponding changes in the C/Nb ratio of the coatings. These data, also given in Table 2-2, show that the processes through IIIa had C/Nb ratios around 0.90. The more recent processes have C/Nb ratios of about 0.86. A check of an element from L349 shows that the values obtained with Type VII parameters are consistent from one end of the element to the other.

(CRD) For NbC GEM coating of the Pewee 2 elements, the following parameters were selected. The actual details of the coating operation are described in NCO Procedure 01-09-09, Revision 2, "NbC/GEM One-Step Coating of Fueled Graphite Shapes," October 2, 1969.

Gas Flow, LPME					Time hrs.	Temperature ($\pm 10^\circ\text{C}$)		
Ar	HCl	H ₂	Salt	CH ₄		0	26"	52"
1.80	0.64	0.19	0.10	0.04	8	1060	1150	1290

2.2 (CRD) METALLOGRAPHY (U)

(CRD) Metallographic evaluation of samples from each of the coating runs was the primary tool in following the development of the coating process. Thicknesses were measured metallographically and structures were examined at high magnification on a routine basis. Structures typical of those given by the Pewee 2 coating parameters are shown in Figure 2-2. Note the dense layer adjacent to graphite past the mid-band of the element and the very fine columnar structure in the mid-band area.

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(CRD) Time consuming crack counts were not done on a routine basis, but a count was made on a fuel element considered to be typical of a Pewee 2 production element. An extensive study of crack density was undertaken as part of Phase IV-B⁽¹⁾ because cracks were the most prevalent coating defect responsible for the corrosion of the graphite matrix, especially in the mid-band area. An NbC GEM coating batch (WEFF, B229) showed a particular relationship of crack density to coating thickness. As the coating thickness increased, the number of cracks was observed to decrease, presumably because the thicker coatings are stronger and, therefore, do not crack as readily due to stresses resulting from the GEM coating temperature. A corresponding crack count was made on an element from L349 representing the Pewee 2 process. The crack density for this element is fairly constant relative to thickness and almost a factor of ten lower than on the Phase IV-B element. This reflects changes in the matrix materials and the coating structure and represents (as evidenced by corrosion tests) an overall improvement in coating-matrix compatibility. The crack densities for these two elements are compared in Figure 2-3.

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TABLE 2-1

(CRD) TS-3012 AND TS-3017 GEM NbC RUNS BY PARAMETER TYPE (U)

Note: Run time shown in parentheses.

<u>Phase IVB</u>	<u>LASL-I</u>	<u>LASL-II</u>	<u>LASL-IIIa</u>	<u>WNCO-IIIb</u>	<u>WNCO-IV</u>	<u>WNCO-V</u>	<u>WNCO-VI</u>	<u>WNCO-VII</u>
C408 (14)	C416 (7)	C419 (7)	C437 (7)	L325 (8)	L332 (7)	L334 (7)	L337 (7)	L349 (10)
C409 (14)	C417 (7)	C421 (7)	C438 (7)	L327 (8)	L333 (7)	L342 (7)	L343 (7)	L350 (9)
C410 (14)	C428 (7)	C422 (7)	C439 (7)	L328 (8)	L335 (7)	L346 (7.5)	L345 (7)	L351 (10)
C412 (14)	C429 (7)		C441 (8)	L329 (7)	L336 (7)	L347 (7)		L352 (8.5)
C413 (14)	C432 (7)		C442 (4.5)	L330 (7)		L348 (7)		L353 (7)
C415 (14)			C444 (4)	L331 (7)				L354 (7.5)
								L355 (8.5)
								L357 (8.5)
								L358 (8.5)
								L359 (7)
								L360 (7)
								L361 (8)
								L362 (7)
								L363 (7)
								L364 (8)

TABLE 2-2

(CRD) NbC GEM COATING BY TYPE (U)

Phase/ Type	Gas Flow, LPME					Temperature °C			Rate gms/hr	Thickness Profile, mils/hr						C/Nb Station 22/50
	Ar	HCl	H ₂	Salt	CH ₄	SP 2	SP 3	SP 4		4.5	13.5	22.5	31.5	40.5	49.5	
IVB	4.50	.75	.18	.09	.06	1029 + 3	1062 + 4	1081 + 3	4.3 + 0.5	.08 + .01	.07 + .01	.08 + .01	.10 + .01	.11 + .01	.09 + .01	-/-
I	1.77 + .02	.56	.19	.08 + .01	.04	1079 + 3	1177 + 4	1303 + 7	10.0 + 0.7	.14 + .04	.22 + .05	.26 + .04	.25 + .04	.23 + .04	.17 + .02	.86/.90
II	1.78 + .02	.56	.19	.08 + .01	.04	1081 + 3	1146 + 5	1289 + 15	8.4 + 1.1	.09 + .02	.13 + .02	.16 + .04	.21 + .06	.22 + .04	.24 + .03	.94/.90
IIIa	1.77 + .03	.56	.19	.08 + .01	.04	1080 + 3	1179 + 2	1325 + 2	10.2 + 1.3	.12 + .02	.21 + .02	.25 + .03	.26 + .04	.23 + .05	.20 + .06	.87/.89
IIIb	1.79 + .03	.64	.19	.09 + .01	.04	1084 + 4	1175 + 2	1320 + 11	12.3 + .7	.20 + .04	.30 + .02	.27 + .02	.28 + .03	.32 + .04	.30 + .04	.86/.86
IV	1.79 + .01	.64	.19	.10 + .01	.04	1083 + 3	1190 + 4	1308 + 4	11.9 + 1.0	.26 + .03	.37 + .02	.28 + .02	.25 + .03	.23 + .04	.17 + .04	.87/.89
V	1.80 + .01	.64	.19	.10 + .01	.04	1087 + 4	1183 + 2	1341 + 3	12.1 + .6	.24 + .02	.34 + .03	.28 + .02	.29 + .02	.28 + .03	.22 + .02	.87/.86
VI	1.79 + .01	.64	.19	.09 + .01	.04	1061 + 1	1170 + 5	1328 + 4	12.4 + 1.0	.14 + .02	.27 + .02	.28 + .01	.33 + .01	.37 + .02	.32 + .03	.87/.87
VII	1.80 + .01	.64	.19	.10 + .01	.04	1062 + 3	1150 + 2	1289 + 3	11.9 + .5	.16 + .02	.26 + .02	.27 + .02	.30 + .01	.34 + .04	.31 + .04	.86/.86
NbC Minimum Coating Profile ÷ 8 hrs.									10.4 + 2.1	.12	.21	.22	.22	.22	.22

Phase IV-B
G103 (WEFF)

LASL Type
C437 (WNCO)

WNCO Modification
L361 (WNCO)

Figure 2-1. (CRD) Microstructures of GEM NbC Coatings at Station 22 Deposited From Different Coating Gas Compositions (400X, Etched). (U)

Station 50

Station 30

Station 5

Figure 2-2. (CRD) Microstructure of GEM NbC Coatings From Run L361.
(400X, Etched) Pewee 2 Coating. (U)

Figure 2-3. (CRD) A Comparison of Crack Density Vs. Coating Thickness for PW-1 and PW-2 NbC GEM Coating Processes. (U)

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3.0 (CRD) ZrC HED COATING DEVELOPMENT (U)

3.1 (CRD) PARAMETRIC STUDIES (U)

(U) Development of the HED process began with scoping runs at WEFF under WFDD-TS-3013. This work has since been combined with WFDD-TS-3012 at WNCO.

(CRD) The aim of these programs was to deposit a film of ZrC by a diffusion process over the GEM NbC basecoat from station 35 to 52. Deposition of this film without degrading the rest of the element requires a steep temperature gradient in the coating furnace. The hot end temperature must be high enough to deposit a diffusion coating of sufficient thickness while keeping the mid-band temperature below 1300°C . Apparently, if the mid-band temperature exceeds approximately 1300°C , additional coating cracks form upon cooling and degrade mid-band performance. Modifications were made to the furnace coils and insulation to achieve the required gradient.

(CRD) To determine the parameters required for a selected ZrC profile, three sets of runs were made at WEFF. In the first set, gas flows were held constant while the hot end temperature was increased from 1560°C to 1690°C , and to 1750°C . Run time was held constant at 14 hours. The station 50 coating thicknesses for these three runs did not change and were within 0.4 ± 0.1 mil measured metallographically.

(CRD) The second set consisted of three runs with hot end temperature constant at 1740°C with an increase in flow rate of both hydrogen and salt (double and triple). The run time was constant at 14 hours. Station 50 coating thickness measured metallographically again did not vary, and fell within 0.4 ± 0.1 mil.

(CRD) The third set consisted of two runs in which only salt flow was varied (hydrogen to salt ratios 5 and 10). As with the first two sets of runs, the station 50 thickness was within 0.4 ± 0.1 mil.

(CRD) It is apparent from these results that to obtain a significant change in coating thickness a large change in the hydrogen to salt ratio was required (perhaps 50 to 100) or the hot end temperature must be increased above 1750°C .

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(CRD) It was at this point that coating technology was transferred to WNCO. The initial six runs were made in F furnace and the remaining 21 runs were made in M furnace. A tabulation of coating data for each run is given in Appendix B, Table 2. The nominal coating conditions are given below:

Gas Flow, LPME			Time hrs.	Temperature (°C)		
<u>Ar</u>	<u>H₂</u>	<u>Salt</u>		<u>0</u>	<u>26</u>	<u>52</u>
2.34	0.33	0.042	20	1103	1352	1747

The process is very reproducible and the above parameters give deposition weight gains of about 8 grams with thicknesses ranging from 0.0 to 0.2 mil at 30 inches to 0.7 to 1.1 mils at 50 inches. The actual weights and thicknesses of the coatings on individual elements are functions of the hot end temperatures and the thickness and carbon content of the NbC GEM basecoat. The relationship between the final duplex coating thickness and the thickness of the NbC GEM basecoat is shown in Figure 3-1.

(CRD) For ZrC HED coating of the Pewee 2 elements, the following parameters were recommended. The actual details of the coating operation are described in NCO Procedure 01-09-07, Revision 1, "ZrC/HED One-Step Coating of Fueled Graphite Shapes," September 15, 1969.

Gas Flow, LPME			Time hrs.	Temperature (+ 10°C)		
<u>Ar</u>	<u>H₂</u>	<u>Salt</u>		<u>0</u>	<u>26</u>	<u>52</u>
2.40	0.33	0.04	20	1100	1350	1750

3.2 (CRD)METALLOGRAPHY AND X-RAY DATA (U)

(CRD) Coating thickness was measured routinely at high magnification. The typical metallographic appearance of a ZrC HED coating over a GEM NbC basecoat is shown in Figure 3.2. A light etch reveals that the ZrC is made up of coarse columnar grains with irregular grain boundaries. In order to develop the NbC structure, a heavy etch is required and it dissolves the ZrC coating. Figure 3.3 shows the structure of the NbC

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before and after ZrC HED coating. This duplex coating is characterized by an excellent ZrC-NbC bond, grain growth of the NbC coating, and no apparent degradation of the NbC-graphite interface at ZrC thicknesses of less than 0.8 mil.

(CRD) In addition to changing the structure of the NbC basecoat, overcoating the hot end of NbC GEM coated elements with a ZrC diffusion coating causes changes to occur in the stoichiometry of the NbC coating. The x-ray data in Table 3-1 show that the diffusion overcoating operation causes the average C/Nb ratio at stations 22 and 49 to increase from 0.87 to 0.93 and 0.87 to 0.91, respectively. Because the temperature at station 49 is 400°C higher during coating than the temperature at station 22, a greater increase in the C/Nb ratio (due to more active carbon diffusion) would be expected at station 49 than at station 22. Apparently, carbon build-up does not occur because of the use of the diffused carbon in forming the ZrC overcoating.

(CRD) The ZrC lattice parameter averages 4.697. Figure 3-4 shows the lattice parameter as a function of composition. By assuming that diffusion conditions are represented by the left side of the curve, 4.697 corresponds to a C/Zr of 0.78 and ranges from 0.77 to 0.84 (4.695 to 4.701).

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TABLE 3-1

(CRD) NbC GEM/ZrC HED X-RAY DATA (CRD)

Run No.	C/Nb Ratios						"Q" Lattice	
	Station 22			Station 49			Sta. 22	Sta. 49
	As NbC	As Q	Δ	As NbC	As Q	Δ		
C413/F405	--	--	--	--	--	--	--	--
C417/F407	--	.95	--	--	.92	--	--	4.695
C419/F408	--	.95	--	--	.92	--	--	4.698
C421/F409	.95	.95	.00	.88	.95	+07	--	4.696
C437/F424	.87	.95	+08	.90	.94	+04	--	4.697
C438/M149	.88	.95	+07	.91	.94	+03	--	4.695
C439/M150	.86	.95	+09	.88	.94	+06	--	4.695
L328/M151	.86	.95	+09	.86	.92	+06	--	4.696
L333/M159	.86	.85	-.01	.85	.93	+08	--	4.701
L343/M164	.88	.91	+03	.87	.84	-.03	--	4.695
L346/M165	.87	.91	+04	.86	.91	+05	--	4.700
L346/M166	.87	.95	+08	.86	.92	+06	--	4.698
L347/M167	.86	.95	+09	.86	.92	+06	--	4.698
L349/M169	.86	.95-.84		.86	.92	+06	--	4.695
L351/M170	.86	.95-.84		.86	.91	+05	--	4.696
L354/M173	.86	.95-.84		.86	.92	+06	--	4.696
L353/M174	.86	.88	+02	.86	.91	+05	--	4.699
L355/M175	.86	.88	+02	.86	.91	+05	--	4.701
L357/M177	.86	.93	+07	.86	.90	+04	--	4.699
L357/M178	.86	.95-.84		.86	.91	+05	--	4.700
L361/M179	.86	.82	-0.04	.86	.91	+05	--	4.700
L360/M180	--	.94	--	--	.91	--	--	4.699
L362/M181	.87	.94	+07	.87	.91	+04	--	4.699
L358/M182	.86	.94	+08	.86	.89	+03	--	4.700
T173/M183	.86	.91		.86	.91		--	4.700
L364/M184	.86	.92	+06	.86	.90	+04	--	4.700
Average	.87	.93	+0.05	.87	.91	+0.05	--	4.697

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Figure 3-1. (CRD) Relationship Between Final Coating Thickness After ZrC Deposition By HED Process and GEM NbC Thickness (20 hours, 1750°C Hot End and 1350°C Mid-Band). (CRD)

(a) Unetched, 400X; Transverse View of Channel 10 at 49.5 Inches of Element No. 09-30569 from C413/F408

(b) Etched, 400X; Transverse View of Channel 10 at 49.5 Inches of Element No. 000-1048430 from L357/M178

Figure 3-2. (CRD) ZrC HED Coating Structure Over an NbC GEM Basecoat. (CRD)

(a) NbC GEM Structure as Deposited; Etched, 400X; Transverse View of Channel 10 at 49.5 Inches of Element No. 000-1034643 from C419.

(b) NbC GEM Structure After ZrC HED Coating; Etched for NbC, 400X, Transverse View of Channel 10 at 49.5 Inches of Element No. 000-1038467 from C419/F408.

Figure 3-3. (CRD) Structure of NbC GEM Basecoat Before and After ZrC HED Overcoating. (CRD)

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Figure 3-4. (U) Lattice Parameter Versus Stoichiometry of Zirconium Carbide.

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4.0 (CRD) ZrC GEM COATING DEVELOPMENT (U)

4.1 (CRD) ZrC GEM OVERCOATING (U)

(CRD) Test Specification WFDD-TS-3017 was established to cover development of a ZrC GEM overcoat to give a combination that was possibly more desirable than NbC GEM/ZrC HED coatings for elements made from high expansion graphites. Therefore, at the start of work on this test specification, the NbC GEM/ZrC GEM coating combination was considered as the prime coating process for Pewee 2 elements. However, the performance of elements coated by the NbC GEM/ZrC GEM process was unpredictable in corrosion tests for reasons that could not be resolved in time for the Pewee 2 core production.

(CRD) The detailed ZrC GEM coating data are shown in Appendix B-3. A study of the data indicates that the ZrC GEM overcoating process parameters have gone through three iterations. These are shown below:

Process Type	Gas Flow (LPME)				Time hrs.	Temperature (°C)		
	Ar	H ₂	Salt	CH ₄		SP-1 (1")	SP-2 (26")	SP-3 (52")
Q1	2.65	0.25	0.03	0.04	10	925	1050	1225
Q2	2.71	0.33	0.06	0.02	10	885	1060	1175
Q3	2.74	0.33	0.06	0.02	7	985	1150	1280-1320

(CRD) The first of these gives a structure that is fine-grained and randomly oriented with a tendency for laminations that are parallel to the bore axis. It appears that the laminations are caused by co-deposition of C and ZrC. This chemistry also fails to give an adequate backcoat. The poor backcoat and the possible presence of carbon in the coating suggests an unfavorable salt to methane ratio. This process was used in coating the LCTE elements that were corrosion tested and involved runs F410 through F422. As noted earlier, this coating performed unpredictably in corrosion tests with some of the elements developing large blisters in the coating at 40 to 50 inches. The cause of these blisters is not known, but could possibly be related to the coating structure.

(CRD) Figure 4-1 shows a coating of the first type (Q1) from F416. As an overcoat, this run gave a satisfactory profile. However, the layered structure performed poorly in corrosion tests. In F417 and F418 the inlet hydrogen flow and the mid-band temperature were increased to produce a heavier mid-band coating on some selected elements. The metallography for these runs made it apparent that the salt was depleted before the hot end because the coating at the hot end was a mixture of ZrC grains and soot. This is shown in Figure 4-2. The change in coating conditions was also reflected in a change in the lattice parameter for the coating.

Run No.	Flow of H ₂	Temperature (°C)			Lattice Parameter	
		0	26"	52"	22.5"	49.5"
F416	0.25	915	1050	1225	- - -	4.704
F417	0.33	970	1140	1225	4.706	4.698

(CRD) Following this, the hydrogen and salt concentrations in the inlet gas stream were increased and the methane concentration decreased to give coatings of the second type (Q2) in runs M152 through M155. This change eliminated the problem caused by salt depletion and gave a backcoat that was visually satisfactory. The structure of the deposit using these parameters is shown in Figure 4-3. It is no longer laminar. However, some of the elements with this coating continued to blister in corrosion tests.

(CRD) The third iteration used the same chemistry as the second iteration, but had considerably higher mid-band and hot end coating temperatures and, therefore, shorter run times. The progression from the first to the third iteration yielded a considerable improvement in corrosion test performance and a significant reduction in the frequency of blister formation. Figure 4-4 shows that the resultant structure consists of large grains that have a greater degree of homogeneity than observed in the previous ZrC GEM coatings.

(CRD) The x-ray data shown in Table 4-1 shows that many of the measured parameters exceed the maximum value of 4.702 or a C/Zr of 0.90 shown in Figure 3-3. This is quite possibly due to trace impurities in the lattice. Generally, elements with parameters greater than 4.702 at station 49 performed poorly. Increasing the coating temperature at station 49 dropped the lattice parameter to 4.698 and produced an element that did not blister in the corrosion test. This will be discussed in more detail in the discussion of corrosion test results.

(CRD) As expected, the deposition of ZrC GEM coatings over NbC GEM coatings has less effect upon the structure of the NbC GEM basecoat than ZrC HED overcoating because of the smaller temperature differences in GEM coating. The x-ray data of Table 4-1 show an average increase of only one or two points in the C/Nb as a result of ZrC GEM overcoating.

4.2(CRD) ZrC GEM COATING ON A GRAPHITE SUBSTRATE (U)

(CRD) A small number of runs were made to deposit ZrC GEM coatings on graphite substrates to explore coating parameters and to provide additional data to aid in the solution of the blister problem. These data are shown in Appendix B-4. T142 through T145 are of the Q2 type and M161, F427, and F429 are of the Q3 type. T142 through T144 suffered from salt depletion. The effects of depletion are shown in Figure 4-5. Figure 4-6 shows the coating produced in M161. The high salt flow and the higher hot end temperature gave a very thick hot end coating. As stated above, these runs were exploratory and no attempt was made to control profiles.

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TABLE 4-1

(CRD) NbC GEM/ZrC GEM X-RAY DATA (CRD)

Run No.	C/Nb Ratios						"Q" Lattice	
	Station 22			Station 49				
	As NbC	As Q	Δ	As NbC	As Q	Δ	Sta. 22	Sta. 49
C417/F412	--	.88	--	--	.91	--	----	4.704
C410/F413	--	.88	--	--	.86	--	----	4.702
C410/F414 (F410)	--	.88	--	--	.86	--	----	4.704
C415/F415	--	.87	--	--	.86	--	----	4.700
C424/F416	.95	.95	.00	.95	.95	.00	----	4.704
C430/F417	--	.91	--	--	.95	--	4.706	4.698
C429/F418	.86	.88	.02	.86	.92	.06	4.704	4.698
C431/F419	.91	.95	.04	.91	.92	.01	----	4.704
C431/F420	.91	.92	.01	.91	.92	.01	----	4.702
C431/F421	.91	.92	.01	.91	.92	.01	----	4.704
C430/F422	--	.91	--	--	.91	--	----	4.702
L328/M152	.86	.86	.00	.86	.88	+0.02	----	4.704
C442/4/M153	.88	.90	+0.02	.95/.85	.95/.85	+0.00	----	4.704
L329/M154	.86	.87	+0.01	.86	.87	+0.01	----	4.703
L330/M155	.87	.87	+0.00	.86	.87	+0.01	----	4.701
L328/M156	.86	.86	+0.00	.86	.90	+0.04	----	----
L331/M157	.86	.87	+0.01	--	.86	--	faint	4.698
L332/M158	.87	.87	+0.00	.91/.86	.92/.87	+0.01	faint	4.698
L330/M155	.87	.87	+0.00	.86	.87	+0.01	----	4.701
L334/M160	.86	.87	+0.01	.95/.86	.86	--	----	4.699
L338/M162	.85	.86	+0.01	.86	.85	-0.01	4.703	4.698
L336/M163	.87	.87	+0.00	.90	.92	+0.02	4.707	4.697
L343/M168	.88	.86	-0.02	.87	.92	+0.05	4.709	4.698
Average	.88	.89	+0.01	.88	.90	+0.02	4.706	4.701

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Station 40.5
Bore Coating

Station 49.5
Bore Coating

Station 50.5
Back Coating

Figure 4-1. (CRD) Structure of ZrC GEM Coating From F416 (C424/F416, 400X Etched) (U)

Station 40.5
Bore Coating

Station 49.5
Bore Coating

Station 50.5
Back Coating

Figure 4-2. (CRD) Structure of ZrC GEM Coating From F417 (C430/F417, 400X, Etched). (U)

Station 40.5

Station 49.5

Station 50.5

Figure 4-3. (CRD) Structure of ZrC GEM Coating From M154 (L329/M154, 400X, Etched). (U)

Figure 4-4. (CRD) Structure of GEM ZrC Coating From M158 at Station 49.5
(C432/M158, 400X, Etched). (U)

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a) 13.5 Inches

b) 31.5 Inches

c) 49.5 Inches

d) 50.5 Inches
Exterior Coating

Figure 4-5. (CRD) Effect of Salt Depletion on Deposition of ZrC GEM Coating on Graphite (T143, 400X, Etched). (U)

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Station 13.5

Station 31.5

Station 49.5

Figure 4-6. (CRD) ZrC GEM Coating on a Graphite Substrate (M161, 400X, Etched). (U)

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5.0 (CRD) HYDROGEN CORROSION TESTING OF DEVELOPMENT ELEMENTS (U)

5.1 (CRD) INTRODUCTION (U)

(U) The corrosion elements embodied many different low and high expansion matrices, some of which had variations within themselves. Most of these elements were made for and used in other test programs to evaluate matrix properties. Therefore, there was not a common element type in all coating runs for use in coating evaluation.

(U) The early evaluation data applies almost entirely to coatings deposited on elements that were made from low expansion flour. Also, most of the GEM NbC runs were made in C furnace and the ZrC runs were made in F furnace. The more recent evaluation data applies mostly to coatings deposited on elements made from high expansion flour. Conveniently, the shop rearrangement made it necessary to switch furnaces at about the same time that the emphasis shifted to high expansion elements, and these later GEM NbC runs were made in L furnace and the ZrC runs were made in M furnace.

(U) The detailed corrosion test information is given in Appendix C. Descriptive information on the tests and the performance of the elements is given below.

5.2 (CRD) TEST DESCRIPTIONS (U)

(CRD) The highest temperature hydrogen corrosion testing was performed at test conditions designated as R1.07, R1.08, and R1.09. These tests, all performed at a hydrogen flow rate of 600 SCFM, exit pressures of 435 psig, and approximate power level of 950 KW, differ from one another by mode of test control and by ramp time. The R1.07 test is controlled by combination of hydrogen flow rate and station 49.6 inch temperature (4980°R); the R1.08 and R1.09 tests are controlled by hydrogen flow rate and power. The ramp times of the first two tests is one (1) minute and the R1.09 test utilized three (3) minute ramps. The target of these tests is usually six 10-minute cycles, designated 6 x 10. All hydrogen corrosion tests of high expansion elements were performed with the R1.09 test (3-minute ramps) and the 6-finger hot end chuck to minimize fuel element cracking which occurred at the chuck element contact region.

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(CRD) A small number of D1.01 tests were also performed. This test is performed at the same flow rate and exit pressure as the R1.09 test, but at a lower power level (840 KW) and with one (1) minute ramps using the 6-finger chuck.

(CRD) Other corrosion tests in preparation for Quality Control testing of Pewee 2 fuel production were performed at conditions designated as A6.05, A6.06, and A6.07. These tests are all related to the Quality Control test for NRX-A6 and XE-2 fuel elements (PB 30 + 30) which was slightly modified for Pewee 1 fuel elements (A6.04.). The A6.05 test (flow 600 SCFM, power 880 KW, exit pressure 560 psig) was modified to the A6.06 test by changing exit pressure to the R1.07/08/09 level of 435 psig. The most recent change, to the A6.07 test, was to alter the ramps from one (1) to three (3) minutes, in order to minimize cracking at the chuck contact regions. The 6-finger chuck is used with all A6.05/06/07 testing.

5.3 (CRD) EVALUATION TECHNIQUES (U)

(U) Test data, gross weight losses, visual observations, and photographs from the corrosion test facility provide the initial input for the evaluation of fuel element performance. This is followed up by incremental weight loss measurements for each element by the MULE technique and visual observation of axially sliced elements. In addition to the major inputs provided by the above, electrical resistance measurements were studied and the results related to element performance. The technique provides a resistance value for the coating, R_k , and a resistance component, R_c , that is related to the cracks in the coating and the adherence between the coating and the matrix.

(CRD) Pewee 2 development coating batches showed good uniformity when evaluated using the electrical resistance technique with GEM NbC and GEM ZrC elements exhibiting standard deviations in R_k and R_c of 0.5 to 0.7 milliohms per inch. After HED ZrC over-coating, the sigma values increased to about 1.5 as a result of decreased coating adherence.

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5.4 (CRD) COATING PERFORMANCE IN CORROSION TESTS (U)

(CRD) Elements of six different low expansion matrices and four different high expansion matrices, some of which had variations within themselves, were corrosion tested during the year as part of the coating development program. A number of different corrosion test conditions were employed, but, as stated above, these were mainly variations of the D1.01, A6.04, or R1.07 type of test. NbC GEM, ZrC GEM, NbC GEM/ZrC HED, and NbC GEM/ZrC GEM coated elements were tested with variations in thicknesses of both the basecoats and overcoats. A small number of elements were overcoated with molybdenum.

(CRD) Elements with basecoats using LASL chemistry corrosion tested better than other elements. The LASL-type coatings were almost 2 mils thick in the 10 to 20 inch region, had dense, narrow columnar grains adjacent to the matrix, and were well-rooted. Elements with thinner and less well-rooted basecoats showed greater degrees of pinholing near the hot end that were responsible for larger weight losses.

(CRD) The mid-band performance of elements in the corrosion tests appeared to depend more upon the quality and thickness of the NbC GEM basecoat than on the presence of the molybdenum overcoat. Corrosion test results on the NbC GEM basecoat that will be used on Pewee 2 elements have shown that mid-band corrosion peaks have been eliminated, thereby eliminating the need for molybdenum overcoating. Weight losses in the 0 - 25 inch region of the corrosion tested elements have been consistently very low with the present GEM basecoat.

(CRD) The overall performance of NbC GEM/ZrC HED coated elements was superior to the NbC GEM/ZrC GEM coated elements. The poorer results for NbC GEM/ZrC GEM coated elements reflect tests aborted due to the formation of coating blisters and corrosion pockets at the hot end of the element during the corrosion test. The blister phenomenon was originally associated only with ZrC GEM overcoated elements, but was subsequently observed in a few corrosion tested NbC GEM coated elements, a ZrC GEM coated element, heat treated NbC GEM/ZrC GEM coated elements, and a few ZrC HED overcoated elements.

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Blistered coatings, typical of those in the Pewee 2 development elements, are shown in Figures 5-1 and 5-2.

(CRD) The tendency of NbC GEM/ZrC GEM coated elements to blister has been reduced by changes in ZrC coating parameters (increasing the salt to methane ratio and hot end coating temperature) and may have been eliminated by sufficiently thick coatings. A relationship between the tendency of coatings to blister during the corrosion test and the coating thickness is shown in Figure 5-3. The few NbC GEM/ZrC HED coated elements that blistered came from coating batches with thicknesses that dropped below two mils in the blistered area. Recoating some of these elements in another ZrC HED run to increase hot end thickness completely eliminated blisters.

(CRD) NbC GEM/ZrC HED coated elements that had better than average corrosion test performance came from NbC GEM basecoating runs with 2 or more mils of NbC in the mid-band area. This thickness seems necessary to minimize the frequency of pinhole formation in this part of the element. The hot end weight losses are directly related to the combined NbC plus ZrC coating thicknesses, and minimum thickness of 2.5 mils was established as necessary to give a satisfactory corrosion test result.

(U) The R1.07/08/09 tests were the most severe corrosion tests employed and were used chiefly as a development test for TS-3012 and TS-3017 coatings.

(CRD) The general corrosion characteristics of GEM NbC plus HED or GEM ZrC coated fuel elements in the R1.07/R1.09 test are given below for the mid-band and hot end of the fuel elements and are shown in Figure 5-4.

5.4.1 Mid-band, Station 0-25 (U)

(CRD) The mid-band performance of all elements has been very good, regardless of matrix type. Weight losses have been low (usually less than 1.0 gram in 60 minutes) and gross corrosion has been absent. No fuel elements have failed because of mid-band corrosion problems. The very good mid-band performance is attributed to a reduction in the number of coating cracks by means of a combination of increasing the GEM coat thickness over that of Pewee 1 and also by modifying the coating process to give the so-called LASL

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microstructure, identified in Phase IV-B, Coating Development Studies (WANL-TME-1887). The Phase IV-B studies showed that mid-band weight losses were proportional to the number of GEM coating cracks, and increasing the mid-band coating thicknesses resulted in decreased coating cracks and decreased weight losses.

5.4.2 Hot End, Station 25-50 (U)

(CRD) The hot end portions of fuel elements with GEM NbC plus either HED ZrC or GEM ZrC have given fairly low weight losses with R1.09 testing and in some instances very low weight losses with A6.05/06/07 testing.

(CRD) Station 25-50 weight loss rates for high expansion, AXM and AXF elements which were tested for at least 4×10 minutes at R1.09 test conditions have averaged about 0.15 to 0.17 gram per minute, giving equivalent 60 minute weight losses of 9.0 to 10.2 grams. The lowest 25-50 weight loss rate for R1.09 testing obtained was 0.090 gram per minute (AXM matrix, GEM/HED Q batch L348/M169, R1.09 $2 \times 10 + 1 + 19 + 1.5$).

(CRD) Elements given the A6.05/06/07 tests have had weight loss rates approximately half the value of the R1.09 test. Weight loss rates have been as low as 0.025 gram per minute with typical weight losses ranging from 3 to 6 grams after 6×10 minutes. Typical weight loss profiles for the A6.05/06/07 and the R1.09 tests are compared in Figure 5-5. The weight loss differences are due to an approximately 200°R temperature difference (station 45) between the two basic tests.

(CRD) Three regions of the hot ends, station 25-50, of AXM, AXF, SX5, and GLFI elements have shown sensitivity to cycling, especially with R1.09 testing. The extra corrosion, discernable by both incremental weight loss and by visual inspection, is described below in terms of coating and matrix types.

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5.4.3 Station 25-35 (U)

(CRD) A corrosion peak is seen at about station 30 in the case of some AXM and AXF elements and most of the SX5 and GLFI elements. This peak, occurring at an average surface temperature of 1830°C , is sensitive to power generation level and occurs because of many light corrosion rings seen in Figure 5-4. In some instances, the peak weight losses have been as high as 0.7 gram/inch (60 minutes) and have given an extra 2-3 grams weight loss in the 25-35 region. The peak was found to be related to the number of coating cracks which were determined from the high R_c value seen by the electrical resistance technique. It has been determined both by metallography and electrical resistance studies that the number of coating cracks are related to matrix CTE, coating microstructure, coating thickness, and coating temperature or heat treatment temperature. Thus, an intermediate CTE matrix such as SX5 or GLFI which has more coating cracks than a high CTE matrix and which, with corrosion test cycling, develops still more cracks, is more sensitive to cycling than high CTE matrices which have a relatively small number of coating cracks.

(CRD) Electrical resistance studies of a number of elements that were tested for at least 4×10 minutes at R1.09 conditions showed that gross corrosion occurred when the resistance attributable to coating cracks (R_c) was larger than 1.5 to 2.0 milliohms per inch, which is indicative of a large number of coating cracks. When R_c was lower than 1.5 milliohms per inch, indicating that the number of coating cracks was low, the amount of corrosion was also small.

5.4.4 Station 35-45 (U)

(CRD) Some R1.09 corrosion tested elements have shown a weight loss peak, visible as light ring corrosion or as small corrosion pockets at a surface temperature of approximately 2350°C . These gross effects usually are worst in the region of station 35-40 and with R1.09 testing occasionally result in pinholing. The gross effect also occurs, but to a lesser extent, with elements given the A6.05/06/07 6×10 test. The most severe effects

have been observed in many AXM and AXF elements and, to a lesser extent, with SX5 and GLFI elements. This type of corrosion has given R1.09 corrosion peaks between 0.6-1.2 grams per inch and gave, in some instances, 60 minute weight losses for the 35-45 region which were 2 to 3 grams higher than without these effects. A typical example of this corrosion in an R1.09 test is compared to the corrosion observed in an A6.06 test in Figures 5-5 and 5-6.

5.4.5 Station 42-50 (U)

(CRD) With cyclic R1.09 corrosion testing, SX5 and GLFI elements have exhibited the corrosion rings, ranging from light to severe, which are characteristic of this region, whereas high expansion elements showed either no ring corrosion or at worst only very light rings.

(CRD) This hot end ring corrosion, which appeared to worsen as coating adherence decreased, occurred at temperatures exceeding 2400°C , as indicated by the presence of migrated fuel beads. Studies of the position of the start of bead migration (2400°C) of fuel elements with as-reamed bore diameters of 0.102 inch, Pewee 2 type, showed that with R1.09 testing of either Y-12 or WNCO fuel elements bead migration typically started at station 40 ± 2 inches. For A6.06 tests, migration typically started at approximately 46 inches. For low and intermediate CTE elements, the ring corrosion is believed to be related to a combination of compressive creep of coating, caused by matrix-coating stresses, and resulting in the formation of large coating cracks upon cooldown from a given corrosion test cycle. When coatings are non-adherent, because of the coating type (HED) or the occurrence of diffusion corrosion, the coating cracks may not close completely, resulting in the observed ring corrosion. With high CTE matrices, little or no high temperature matrix-coating interaction occurs and all of the effects are minimized.

(CRD) Another factor which could influence the hot end ring corrosion is a change in matrix properties due to a combination of fuel bead migration and additional graphitization.

Figure 5-1. (CRD) Blisters Formed in Heat Treating a GEM ZrC Coated Element
From C422/3/F412 (S/N 400-2082179; Station 42.3 to 43.3;
~3.5X). (U)

Figure 5-2. (CRD) Longitudinal Section Showing Buckled NbC/ZrC Coatings.
Note Pyrocarbon Deposit Under Buckled Coating (S/N
400-2082210; Station 40, 6X; Coated in C429/F418/AA196,
Corrosion Tested 3 x 10 Minutes in R1.09 Test). (CRD)

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Figure 5-3. (CRD) Blistering of GEM ZrC Coatings Related to Station and Coating Thickness. (CRD)

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Figure 5-4. (CRD) Axially Sliced Corrosion Tested Element With Coating Removed to Illustrate Typical Corrosion of SX-5 Graphite Matrix. (S/N 630-1047607, Coated in L347/M167, Corrosion Tested $3 \times 10 + 1.5 + 18.5 + 0.2$ Minutes in R1.09 Test). (CRD)

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Figure 5-5. (CRD) Comparison of Incremental Weight Losses for R1.09 and A6.07 Tests on GLFI Matrix Elements (U)

Batch L355/M175

Elements	R1.09	166-1048548
	A6.07	166-1048551

A6.06 5 x 10 + 1.0 Minutes
Total Weight Loss 3.0 g
S/N 573-47941, AXM

R1.09 5 x 10 + 4.5 Minutes
Total Weight Loss 7.7 g
S/N 267-47899, AXM

Figure 5-6. (CRD) Comparison Between Effects of R1.09 and A6.06 Testing for AXM Elements From WANL PW-2 Development Batch L351/M170. (U)

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6.0 (CRD) PEWEE 2 COATING DEVELOPMENT (U)

(U) After a review of data collected on properties of development elements, the decision was made in mid-summer 1969 to make Pewee 2 fuel elements from high expansion flour. Therefore, the coating and corrosion test data on AXM elements were analyzed to give the best coating consistent with the Pewee 2 reactor requirements and fuel element specifications. The coating dependent fuel element requirements are listed in Table 6-1.

(CRD) The runs made to develop the Pewee 2 profile are listed in Table 6-2. Gas flows and temperatures were selected to give the desired structure and profile. Time was varied to achieve the desired thickness and weight for the NbC GEM Pewee 2 process. The ZrC HED process for Pewee 2 was unchanged from that used in early development runs. Because corrosion test data indicated that it was more desirable to approach the high side of the specifications, an eight-hour coating time was selected for a maximum hot end thickness and a coating weight below 90 grams of niobium. Figures 6-1 and 6-2 indicated that this process would also meet the air impedance requirements.

(CRD) In order to meet the dimensional requirements, the hot ends of the elements were machined and a bushing designed to control the deposition of coating. An exaggerated view of the hot end of an element machined for coating is shown in Figure 6-3 and fixturing is shown in Figure 6-4. The amount of coating deposited on the flats is dependent upon the amount of coating deposited in the bores and cannot be independently controlled.

As stated before, the parameters and fixturing were selected to provide an NbC GEM bore coating running toward the high side of the specification.

(CRD) Table 6-3 gives data on the corrosion testing of Pewee 2 type AXM elements in the order of testing. With the exception of a few tests, those elements tested at A6.06 conditions ran for 6 x 10 minutes with average weight losses of about 6 grams, most of which occurred in the 40-50 inch region. The elements tested at R1.09 conditions for 6 x 10 minutes showed weight losses averaging 13 grams. As in the A6.06 tests, most of the weight loss occurred in the 40-50 inch region of the elements. A summary of the incremental weight losses is given in Table 6-4.

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(CRD) Based on the results obtained on the coating and corrosion testing of AXM fuel elements, it appears as though the GEM NbC/HED ZrC coating will provide satisfactory protection of the high expansion graphite element in the Pewee 2 reactor.

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TABLE 6-1

(CRD) PEWEE 2 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

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

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

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

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

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

4. Corrosion Test

	A6.07 Prime Q.C. Test
Surface Temp. ($^{\circ}$ R) at Station 49	4800 $\begin{smallmatrix} +100 \\ -150 \end{smallmatrix}$
Time (cycles, time)	6, 60
Weight Loss (gms.)	10
Pinholes Allowed	5

Information Tests
A6.07 6 x 10 Hydrolysis
A6.04 2 x 30
R1.09 6 x 10

TABLE 6-2

(CRD) PEWEE 2 NbC GEM COAT DEVELOPMENT (U)

1. Development runs can be divided into the six groups shown below based on input parameters.

Group I	Group II	Group III	Group IV	Group V	Group VI
L346	L349	L353	L354	L361	L352
L347	L350	L359		L364	L355
L348	L351	L360		L370	L357
		L362		T174	L358
		L363		T182	T173

2. The following nominal gas flows were used for each coating group.

Gas Flow, LPME				
<u>A</u>	<u>HCl</u>	<u>H₂</u>	<u>CH₄</u>	<u>NbCl₅</u>
1.80	0.64	0.19	0.041	0.095

3. Nominal times, temperatures, and weight gains varied as shown below:

Group	Time, hrs.	Temperature - °C			Avg. Wt. Gain, gms.	Avg. Coating Rate, gms./hr.
		<u>0</u>	<u>25</u>	<u>50</u>		
I	7.0	1085	1180	1340	88	12.3
II	10.0	1065	1150	1295	119	12.3
III	7.0	1060	1150	1290	82	11.8
IV	7.5	1060	1150	1290	87	11.6
V	8.0	1060	1150	1290	99	12.4
VI	8.5	1060	1150	1290	99	12.4

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TABLE 6-3
 (CRD) CORROSION TEST DATA (U)
 A6.06 Corrosion Test Sequence (AXM Elements Only)

<u>Test No.</u>	<u>Batch</u>	<u>Cycles</u>	<u>Time</u>	<u>ΔW</u>	<u>Remarks</u>
1.3179	L346/M166	6	60.0	7.2	A6.05, crack.
1.3181	L347/M167	6	60.0	6.1	A6.05, crack.
1.3186	L346/M166	6	5 x 10 + 6.5	5.4	A6.06, spacer corroded, element moved during test.
*1.3190	L346/M166	3	6.0 + 1.5 + 8.0	2.0	A6.06, cracks.
*1.3191	L347/M167	3	2 x 10 + 1.0	1.4	A6.06, cracks.
*1.3194	L348/M169	1	4.5	0.0	A6.06, cracks.
*1.3195	L347/M167	3	2 x 10 + 2.0	2.2	A6.06, broke, corrosion pocket under pins.
*1.3196	L346/M166	4	3 x 10 + 0.5	2.2	A6.06, arcing and corrosion under pins.
1.3202	L349/M169	6	6 x 10	3.5	A6.06, mech. break after test.
1.3203	L347/M167	6	6 x 10	6.4	A6.06, element moved 3/8" during test.
1.3230	L347/M167	5	3 x 10 + 1.5 + 18.5	6.0	A6.06, hydrolyzed - lost seal, crack.
1.3231	L346/M166	6	3 x 10 + 1 + 19 + 10	5.2	A6.06, hydrolyzed.
1.3233	L345/M169	6	6 x 10	6.7	A6.06, 3 minute ramp.
1.3236	L351/M170	6	5 x 10 + 1.0	3.0	A6.06, seal corroded, transverse cracks.
1.3246	L352/M175	6	6 x 10	4.5	A6.06, transverse crack.
1.3249	L354/M175	6	6 x 10	7.4	A6.06, transverse cracks.
1.3260	L355/M175	6	6 x 10	5.9	A6.06
+1.3263	L347/M167	6	6 x 10	13.1	A6.07, many pinholes.
+1.3264	L347/M166	6	6 x 10	13.2	A6.07, two pinholes.
++1.3275	L355/M175	1	10.0	2.7	A6.07, broke on ramp.
1.3276	L351/M170	12	5 x 10 + 7 x 10	20.0	A6.07

- * Tests 1.3190 through 1.3196 were made using a double seal ring and are not representative of a normal A6.06 test.
- + Hydrolyzed elements.
- ++ Retest of element from 1.3260.

TABLE 6-4

(CRD) SUMMARY OF CORROSION TEST RESULTS ON AXM ELEMENTS (U)

Batch	No. of Elements	Avg. Time Element (min.)	Avg. ΔW Element (gms.)	Loss Rate (gm./min.)	MULE Incremental Loss Rate (gm./min.)				
					0-25	25-35	35-40	40-45	45-50
A6.06 TEST									
L345/M169	1	60.0	6.7	0.11	0.003	0.003	0.009	0.013	0.018
L346/M166	6	47.1	5.9	0.12	0.018	0.016	0.018	0.035	0.040
L347/M167	6	45.5	5.9	0.13	0.019	0.016	0.016	0.036	0.038
L348/M169	1	4.5	0.0	----- NO MULE DATA -----					
L349/M169	1	60.0	3.5	0.06	0.011	0.003	0.006	0.011	0.018
L351/M170	2	85.5	11.5	0.13	0.012	0.004	0.010	0.027	0.021
L352/M175	1	60.0	4.5	0.08	0.006	0.003	0.007	0.025	0.023
L354/M175	1	60.0	7.4	0.12	0.013	0.014	0.018	0.044	0.029
L355/M175	1	70.0	8.6	0.12	0.014	0.014	0.021	0.032	0.029
R1.09 TEST									
L345/M169	3	49.8	12.2	0.24	0.030	0.031	0.035	0.043	0.049
L346/M166	3	40.5	8.4	0.22	0.008	0.032	0.030	0.034	0.041
L347/M167	4	41.8	9.8	0.23	0.021	0.034	0.033	0.054	0.046
L348/M169	3	37.1	7.8	0.21	0.012	0.028	0.021	0.046	0.055
L349/M169	1	51.0	8.8	0.17	0.012	0.013	0.022	0.035	0.038
L350/M169	2	60.0	8.5	0.14	0.025	0.036	0.020	0.023	0.032
L351/M170	1	54.5	7.7	0.14	0.014	0.018	0.028	0.046	0.034

Figure 6-1. (CRD) Air Impedance Versus Coating Weight (AXM Elements Only) (U)

Figure 6-2. (CRD) Air Impedance Versus Coating Thickness (AXM Elements Only) (U)

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o BBS Measurements of M179, ZrC HED.

x BBS Measurements of T362, NbC GEM.

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Figure 6-3. (CRD) PW-2 Back Coat and Across-Flats Measurements (U)

b) ZrC HED Bushing

Figure 6-4. (CRD) Photos of Hot End Fixturing (U)

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3. C. R. Simmons, "Performance of WANL Supplied Fuel Elements in Pewee 1," WANL-TME-1937, September, 1969.
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(CRD) APPENDIX A
TEST SPECIFICATIONS 3012 AND 3017 (U)

(CRD) PW-2 DUPLEX COATING DEVELOPMENT - WNCO (U)

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Revision 2

1.0 PURPOSE

(CRD) Study process parameters and fixture designs for producing elements with a GEM (NbC) basecoat/HED (ZrC) hot end overcoat to give maximum performance capability at PW-2 conditions.

2.0 OBJECTIVES

(CRD) 2.1 Establish process and profile information for producing elements with a GEM (NbC) basecoat/HED (ZrC) hot end overcoat.

(CRD) 2.2 Evaluate fixture designs for producing desired back coating profiles for each of the coating processes.

(CRD) 2.3 Provide elements for evaluating corrosion test cyclic performance of a GEM (NbC) basecoat/HED (ZrC) hot end overcoat.

3.0 RAW MATERIALS

(CRD) 3.1 Except for the addition of zirconium tetrachloride, the coating salts and gases will be of the same quality as those used in NbC coating development.

3.2 Matrix

(CRD) For determination of process parameters and fixture design available low-void fueled and non-fueled elements shall be used regardless of their permeability. However, only standard matrix baseline elements with as-leached permeabilities less than 200 cc/min, whole-body air will be employed for assessment of coating-matrix interactions and corrosion test cyclic performance capability.

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4.0 EQUIPMENT CHECK-OUT

4.1 Saturators and Oven

- (CRD) 4.1.1 The need for additional heat input to maintain the higher operating temperatures required to sublime zirconium tetrachloride will be established.
- (U) 4.1.2 The performance of several saturator designs will be evaluated and scale-up considered for production coating.

4.2 Furnaces and Auxiliary Equipment

- (U) 4.2.1 The versatility of the coating furnaces and their ability to meet the operating temperature profile of each of the processes will be explored.
- (U) 4.2.2 The reliability of operating all lines into or out of the furnace above 300°C will be evaluated.

4.3 Traps

- (U) 4.3.1 The capability of removing condensable solids from the process gas stream using existing traps will be determined.

4.4 Fixtures

- (CRD) 4.4.1 Improved seals may have to be developed to prevent impurities from entering the coating gas stream during the deposition of zirconium carbide by a diffusion-controlled process.
- (CRD) 4.4.2 Fixtures have to be designed for each of the coating processes to give the desired back coat thickness and length.

5.0 PARAMETER STUDY

5.1 GEM (NbC Basecoat)

- (CRD) Adjustments will be made to the parameters of time-temperature-gas flow-composition to produce a reasonably flat profile within the following desirable limits:

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5.1 (Continued)

(CRD)	Station	Thickness		Weight gr Nb/in.	
		Min.	Max.	Min.	Max.
	0	1.4	2.7	0.979	1.889
	10	1.8	2.7	1.259	1.889
	15	1.9	2.7	1.329	1.889
	20	2.0	2.7	1.399	1.889
	35	2.0	2.7	1.399	1.889
	50	2.0	3.0	1.399	2.099

(CRD) 5.2 HED (ZrC) Hot End Overcoat

Adjustments will be made to the parameters of time-temperature-gas flow-composition to deposit ZrC between stations 35 and 52 with a profile within the following desirable limits:

Station	Thickness		Weight gr Zr/in.	
	Min.	Max.	Min.	Max.
0	0	0.3	0	0.180
25	0	0.3	0	0.180
35	0	0.8	0	0.479
45	0.3	1.2	0.180	0.719
50	0.5	1.7	0.299	1.020

5.3 Duplex Coating

(CRD) The combined coatings deposited in items 5.1 and 5.2 shall fall in the range of 2.5 to 3.5 mils at station 50.

6.0 REPRODUCIBILITY

(U) After parameters are developed to give coating profiles that correspond to the latest revision of the Pewee 2 fuel element drawing, a series of runs will be made in each of the coating furnaces to demonstrate the reproducibility of operating conditions to give the desired product.

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7.0 INSPECTION AND EVALUATION

- (U) 7.1 The following requirements pertain to every coating batch regardless of whether non-fuel or a mixture of non-fuel and fuel elements is employed.
- (U) 7.1.1 Prior to NbC Coating
- (U) 7.1.1.1 Visual for holes, cracks, and chips - all elements.
- (CRD) 7.1.1.2 Across flats dimensions at the following distances from the hot end: 1/16, 3/4, 1, 1-1/2, 2-1/2, 4, 6, 27, and 47 - selected elements.
- (U) 7.1.1.3 Whole body air leak test (as leached) - all fuel elements.
- (CRD) 7.1.1.4 Incremental helium leak test if whole body air value is greater than 100 cc/min - all fuel elements.
- (U) 7.1.1.5 Incremental electrical resistance - all fuel elements.
- (U) 7.1.1.6 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.2 After NbC Coating
- (U) 7.1.2.1 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.2.2 Metallographic examination of at least one element from each coating batch for determination of coating profile and appearance.
- (CRD) 7.1.2.3 NbC stoichiometry in the bore at 20 and 50 inches from the metallographic element.
- (CRD) 7.1.2.4 Across flats measurements on the three flats at the following distances from the hot end: 1/16 and 3/4 - selected elements.
- (U) 7.1.2.5 Internal coating thickness by beta backscatter - all fuel and selected non-fuel elements.
- (CRD) 7.1.2.6 External coating thickness by microderm at the following distances from the hot end: 1/8, 1/4, 3/8, and 3/4 - standard tipped fuel and selected non-fuel elements.

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- (U) 7.1.2.7 Incremental electrical resistance - all fuel elements.
- (U) 7.1.2.8 Air impedance measurements - all fuel elements.
- (CRD) 7.1.3 After ZrC Coating
- (U) 7.1.3.1 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.3.2 Metallographic examination of at least one element from each coating batch for determination of coating profile and appearance.
- (CRD) 7.1.3.3 NbC stoichiometry and ZrC lattice parameter in the bore at 20 and 50 inches from the metallographic element.
- (CRD) 7.1.3.4 Across flats measurements on the three flats at the following distances from the hot end: 1/16, 3/4, 1, 1-1/2, 2-1/2, 4, 6, 26, and 47 - selected elements.
- (U) 7.1.3.5 Internal coating thickness by beta backscatter - corrosion test candidates and selected non-fuel elements.
- (CRD) 7.1.3.6 External coating thickness by microderm at the following distances from the hot end: 1/8, 1/4, 3/8, 3/4, 1-1/2, 2-1/2, and 3-1/2 on standard tipped corrosion test candidates and selected non-fuel elements and at 3/4, 1-1/2, 2-1/2, and 3-1/2 in composite tipped corrosion test candidates.
- (U) 7.1.3.7 Incremental electrical resistance - corrosion test candidates.
- (U) 7.1.3.8 Air impedance measurement - corrosion test candidates.
- (U) 7.1.3.9 Mule - all corrosion test candidates.
- (U) 7.1.4 After Corrosion Testing
- (U) 7.1.4.1 Element weight, total.
- (U) 7.1.4.2 Mule or element weight, 5" increment.
- (U) 7.1.4.3 Incremental electrical resistance.
- (U) 7.1.4.4 Metallographic examination.

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- (U) 7.1.4.5 Visual examination of longitudinal slice sections.
- (U) 7.1.4.6 Air impedance measurements - all fueled elements.

8.0 CORROSION TESTING

- (U) 8.1 Selected elements will be tested by the applicable corrosion test.
- (CRD) 8.2 Corrosion test candidates must have a leak rate of less than 200 cc/min, whole body, air, as-leached.
- (CRD) 8.3 The minimum total coating thickness requirements for corrosion test candidacy shall be 2.0 mils at station 20 and 2.5 mils at station 50.
- (CRD) 8.4 For a comparative evaluation, some elements may be molybdenum overcoated before corrosion testing.
 - (CRD) 8.4.1 The following measurements are required after molybdenum overcoating:
 - (U) 8.4.1.1 Incremental electrical resistance - all fuel elements.
 - (U) 8.4.1.2 Air impedance measurements - all fuel elements.
 - (U) 8.4.1.3 Element weight - all fuel elements.
 - (U) 8.4.1.4 Visual inspection - all fuel elements.
 - (U) 8.4.1.5 Mule - all corrosion test candidates.

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Revision 1

(CRD) PW-2 DUPLEX COATING DEVELOPMENT - WNCO (U)

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1.0 PURPOSE

(CRD) Study process parameters and fixture designs for producing elements with a GEM (NbC) basecoat/GEM (ZrC) overcoat to give maximum performance capability of high expansion matrices at PW-2 conditions.

2.0 OBJECTIVES

- (CRD) 2.1 Establish process and profile information for producing elements with a GEM (NbC) basecoat/GEM (ZrC) overcoat.
- (CRD) 2.2 Evaluate fixture designs for producing desired back coating profiles for each of the coating processes.
- (CRD) 2.3 Provide elements for evaluating corrosion test cyclic performance of a GEM (NbC) basecoat/GEM (ZrC) overcoat.

3.0 RAW MATERIALS

(CRD) 3.1 Except for the addition of zirconium tetrachloride, the coating salts and gases will be of the same quality as those used in NbC coating development.

(CRD) 3.2 Matrix

For determination of process parameters and fixture design available low-void fueled and non-fueled elements shall be used regardless of their permeability. However, only elements with as-leached permeabilities less than 200 cc/min, whole-body air will be employed for assessment of corrosion test cyclic performance capability.

4.0 FIXTURES

- (CRD) 4.1 Improved seals may have to be developed to prevent impurities from entering the coating gas stream during the deposition of zirconium carbide.
- (CRD) 4.2 Fixtures have to be designed for each of the coating processes to give the desired back coat thickness and length.

5.0 PARAMETER STUDY

(CRD) 5.1 GEM (NbC) Basecoat

Adjustments will be made to the parameters of time-temperature-gas flow-composition to produce a profile within the following limits:

Station	Thickness		Weight gr Nb/in.	
	Min.	Max.	Min.	Max.
0	1.4	2.7	0.979	1.889
10	1.8	2.7	1.259	1.889
15	1.9	2.7	1.329	1.889
20	2.0	2.7	1.399	1.889
35	2.0	2.7	1.399	1.889
50	2.0	3.0	1.399	2.099

(CRD) 5.2 GEM (ZrC Overcoat)

Adjustment will be made to the parameters of time-temperature-gas flow-composition to produce a profile within the following limits:

Station	Thickness		Weight gr Zr/in.	
	Min.	Max.	Min.	Max.
0	0	0.5	0	0.289
10	0	0.5	0	0.289
20	0	0.5	0	0.289
25	0	1.0	0	0.577
45	0.3	1.4	0.173	0.808
50	0.5	2.0	0.289	1.154

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(CRD) 5.3 Duplex Coating

The combined coatings deposited in items 5.1 and 5.2 shall fall in the range of 2.5 to 3.5 mils at station 50.

6.0 REPRODUCIBILITY

- (U) After parameters are developed to give coating profiles that correspond to the latest revision of the Pewee 2 fuel element drawing, a series of runs will be made in each of the coating furnaces to demonstrate the reproducibility of operating conditions to give the desired product.

7.0 INSPECTION AND EVALUATION

- (U) 7.1 The following requirements pertain to every coating batch regardless of whether non-fuel or a mixture of non-fuel and fuel elements is employed.
- (U) 7.1.1 Prior to NbC Coating
- (U) 7.1.1.1 Visual for holes, cracks, and chips - all elements.
- (CRD) 7.1.1.2 Across-flats dimensions at the following distances from the hot end: 1/16, 3/4, 1, 1-1/2, 2-1/2, 4, 6, 27, and 47 - selected elements.
- (U) 7.1.1.3 Whole body air leak test (as-leached) - all fuel elements.
- (CRD) 7.1.1.4 Incremental helium leak test if whole body air value is greater than 100 cc/min - all fuel elements.
- (U) 7.1.1.5 Incremental electrical resistance - all fuel elements.
- (U) 7.1.1.6 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.2 After NbC Coating
- (U) 7.1.2.1 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.2.2 Metallographic examination of at least one element from each coating batch for determination of coating profile and appearance.

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- (CRD) 7.1.2.3 NbC stoichiometry in the bore at 20 and 50 inches from the metallographic element.
- (CRD) 7.1.2.4 Across flats measurements on the three flats at the following distances from the hot end: 1/16 and 3/4 - selected elements.
- (U) 7.1.2.5 Internal coating thickness by beta backscatter - all fuel and selected non-fuel elements.
- (CRD) 7.1.2.6 External coating thickness by microderm at the following distances from the hot end: 1/8, 1/4, 3/8, and 3/4 - standard tipped fuel and selected non-fuel elements.
- (U) 7.1.2.7 Incremental electrical resistance - all fuel elements.
- (U) 7.1.2.8 Air impedance measurements - all fuel elements.
- (CRD) 7.1.3 After ZrC Coating
- (U) 7.1.3.1 Element weight - all fuel and selected non-fuel elements.
- (U) 7.1.3.2 Metallographic examination of at least one element from each coating batch for determination of coating profile and appearance.
- (CRD) 7.1.3.3 NbC stoichiometry and ZrC lattice parameter in the bore at 20 and 50 inches from the metallographic element.
- (CRD) 7.1.3.4 Across flats measurements on the three flats at the following distances from the hot end: 1/16, 3/4, 1, 1-1/2, 2-1/2, 4, 6, 26, and 47 - selected elements.
- (U) 7.1.3.5 Internal coating thickness by beta backscatter - corrosion test candidates and selected non-fuel elements.
- (CRD) 7.1.3.6 External coating thickness by microderm at the following distances from the hot end: 1/8, 1/4, 3/8, 3/4, 1-1/2, 2-1/2, and 3-1/2 on standard tipped corrosion test candidates and selected non-fuel elements and at 3/4, 1-1/2, 2-1/2, and 3-1/2 on composite tipped corrosion test candidates.

- (U) 7.1.3.7 Incremental electrical resistance - corrosion test candidates.
- (U) 7.1.3.8 Air impedance measurement - corrosion test candidates.
- (U) 7.1.3.9 Mule - all corrosion test candidates.
- (U) 7.1.4 After Corrosion Testing
- (U) 7.1.4.1 Element weight, total.
- (U) 7.1.4.2 Mule or element weight, 5" increment.
- (U) 7.1.4.3 Incremental electrical resistance.
- (U) 7.1.4.4 Metallographic examination.
- (U) 7.1.4.5 Visual examination of longitudinal slice sections.
- (U) 7.1.4.6 Air impedance measurements.

8.0 CORROSION TESTING

- (U) 8.1 Selected elements will be tested by the applicable corrosion test.
- (CRD) 8.2 Corrosion test candidates must have a leak rate of less than 200 cc/min, whole body, air, as-leached.
- (CRD) 8.3 The minimum total coating thickness requirements for corrosion test candidacy shall be 2.0 mils at station 20 and 2.5 mils at station 50.
- (CRD) 8.4 For a comparative evaluation, some elements may be molybdenum overcoated before corrosion testing.
- (CRD) 8.4.1 The following measurements are required after molybdenum overcoating:
 - (U) 8.4.1.1 Incremental electrical resistance - all fuel elements.
 - (U) 8.4.1.2 Air impedance measurements - all fuel elements.
 - (U) 8.4.1.3 Element weight - all fuel elements.
 - (U) 8.4.1.4 Visual Inspection - all fuel elements.
 - (U) 8.4.1.5 Mule - all corrosion test candidates.

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APPENDIX B

(CRD) COATING DATA (U)

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TABLE B-1
 (CRD) NbC GEM COATING RUNS BY TYPE (U)

Phase Type	Run No.	Gas Flow, LPME					Temperature °C			Time hrs.	Weight gms.	Thickness, mils						C/Nb Station 22/50
		Ar	HCl	H ₂	SnI ₂	CH ₄	0"	26"	52"			4.5	13.5	22.5	31.5	40.5	49.5	
IVB	C408	4.50	.75	.18	.09	.06	----	----	----	14	----	----	----	----	----	----	----	--/--
	C409	4.50	.75	.18	.09	.06	1025	1060	1080	14	50.2	.95	.82	.98	1.21	1.35	1.40	--/--
	C410	4.50	.75	.18	.09	.06	1030	1055	1080	14	52.7	----	----	----	----	----	----	--/--
	C412	4.50	.75	.18	.09	.06	1025	1065	1085	14	66.4	----	----	----	----	----	----	--/--
	C413	4.50	.75	.18	.09	.06	1030	1065	1085	14	69.3	1.23	1.09	1.31	1.52	1.61	1.29	--/--
	C415	4.50	.75	.18	.09	.06	1035	1065	1075	14	60.2	1.18	1.09	1.20	1.20	1.33	1.00	--/--
I	C416	1.77	.56	.19	.07	.04	1074	1183	1286	7	73.0	.71	1.24	1.77	2.03	1.86	1.33	--/--
	C417	1.78	.56	.19	.08	.04	1077	1178	1306	7	78.0	1.33	2.12	2.46	2.28	2.02	1.38	--/--
	C428	1.78	.56	.19	.08	.04	1080	1175	1305	7	61.2	.72	1.20	1.45	1.47	1.31	1.24	.86/.91
	C429	1.79	.56	.19	.08	.04	1080	1170	1310	7	67.0	.90	1.50	1.64	1.66	1.56	1.29	.86/.86
	C439	1.71	.56	.19	.11	.04	1085	1180	1310	7	70.9	1.34	1.91	1.82	1.61	1.33	.97	.86/.92
II	C419	1.78	.56	.19	.07	.04	1082	1153	1312	7	70.0	.87	1.15	1.54	2.12	1.95	2.00	--/--
	C421	1.77	.56	.19	.08	.04	1075	1140	1275	7	53.5	.41	.60	.79	.99	1.33	1.56	.95/.88
	C422	1.78	.56	.19	.09	.04	1085	1145	1280	7	52.4	.71	.88	1.10	1.34	1.42	1.45	.92/.92
IIIa	C437	1.72	.56	.19	.07	.04	1080	1180	1330	7	57.7	.72	1.20	1.45	1.56	1.40	1.12	.87/.90
	C438	1.79	.56	.19	.08	.04	1078	1175	1320	7	60.0	.72	1.22	1.50	1.45	1.13	.88	.88/.91
	C439	1.71	.56	.19	.08	.04	1080	1180	1324	7	67.6	.80	1.50	1.71	1.75	1.29	1.18	.86/.88
	C441	1.81	.56	.19	.09	.04	1075	1180	1325	8	88.0	1.08	2.16	2.42	2.33	1.80	1.79	.86/.85
	C442	1.78	.56	.19	.08	.04	1090	1180	1325	4.5	46.1	.79	.97	1.08	1.17	1.01	.74	.88/.94
	C444	1.79	.56	.19	.08	.04	1079	1178	1327	4	53.2	.39	.83	1.18	1.40	1.52	1.31	.86/.86
IIIb	L325	1.77	.64	.19	.08	.04	1087	1181	1329	8	100.8	1.70	2.35	2.16	2.16	2.49	2.48	.86/.87
	L327	1.78	.64	.19	.08	.04	1080	1175	1335	8	99.9	1.31	2.14	2.25	2.37	2.90	2.58	.87/.86
	L328	1.79	.64	.19	.10	.04	1079	1175	1297	8	93.7	1.63	2.41	1.91	1.84	1.87	1.98	.86/.86
	L329	1.79	.64	.19	.09	.04	1090	1175	1330	7	97.7	1.68	2.35	2.19	2.09	2.23	1.80	.86/.86
	L330	1.79	.64	.19	.09	.04	1085	1175	1310	7	79.5	1.79	2.09	1.71	1.73	2.02	1.96	.87/.87
	L331	1.79	.64	.19	.09	.04	1080	1170	1320	7	82.9	.99	1.86	1.87	2.19	2.71	2.83	.86/--

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TABLE B-1 (Cont'd)
(CRD) NbC GEM COATING RUNS BY TYPE (U)

Phase Type	Run No.	Gas Flow, LPME					Temperature °C			Time hrs.	Weight gms.	Thickness, mils						C/Nb Station 22/50
		Ar	HCl	H ₂	Salt	CH ₄	0"	26"	52"			4.5	13.5	22.5	31.5	40.5	49.5	
IV	L332	1.80	.64	.19	.10	.04	1087	1192	1310	7	86.6	2.09	2.81	1.89	1.84	1.68	.88	.87/.91
	L333	1.80	.64	.19	.10	.04	1077	1186	1300	7	94.1	1.64	2.46	2.23	2.02	2.00	1.73	.86/.85
	L335	1.78	.64	.19	.09	.04	1085	1195	1314	7	74.1	1.86	2.62	1.77	1.56	1.22	.90	.86/.91
	L336	1.77	.64	.19	.10	.04	1083	1186	1307	7	78.9	1.71	2.37	1.87	1.64	1.56	1.22	.87/.90
V	L334	1.78	.64	.19	.10	.04	1098	1183	1343	7	90.2	1.70	2.58	2.05	2.32	2.19	1.68	.86/.86
	L342	1.79	.64	.19	.09	.04	1084	1183	1335	7	75.6	1.52	2.07	1.70	1.73	1.54	1.34	.90/.86
	L346	1.80	.64	.19	.09	.04	1087	1185	1347	7.5	92.4	2.00	2.51	2.00	2.26	2.23	1.73	.87/.86
	L347	1.81	.64	.19	.11	.04	1083	1179	1341	7	86.7	1.84	2.56	2.03	1.96	2.21	1.64	.86/.86
	L348	1.80	.64	.19	.10	.04	1085	1186	1341	7	85.8	1.45	2.23	2.05	2.05	2.00	1.31	.86/.86
VI	L337	1.78	.64	.19	.10	.04	1063	1162	1326	7	97.1	1.24	1.91	1.93	2.19	2.81	2.49	.87/.87
	L343	1.79	.64	.19	.09	.04	1061	1172	1324	7	84.7	.95	2.12	2.00	2.44	2.42	2.00	.87/.87
	L345	1.80	.64	.19	.09	.04	1059	1175	1333	7	84.8	.77	1.71	1.82	2.28	2.47	2.20	.87/.87
VII	L349	1.79	.64	.19	.09	.04	1072	1151	1301	10	113.2	1.62	2.22	2.42	2.79	3.36	3.31	.86/.86
	L350	1.80	.64	.19	.10	.04	1068	1143	1301	9	127.5	1.30	1.69	1.91	2.70	3.93	4.28	.86/.86
	L351	1.81	.64	.19	.10	.04	1060	1150	1290	10	115.4	1.87	2.88	2.71	2.81	3.01	2.65	.86/.86
	L352	1.79	.64	.19	.10	.04	1058	1152	1288	8.5	96.6	1.27	2.32	2.58	2.94	2.90	2.76	.86/.86
	L353	1.83	.64	.19	.09	.04	1061	1152	1289	7	82.4	1.25	2.00	1.82	2.03	2.18	1.91	.86/.86
	L354	1.79	.64	.19	.10	.04	1059	1151	1292	7.5	86.8	1.38	2.07	2.05	2.07	2.21	1.86	.86/.86
	L355	1.82	.64	.19	.09	.04	1060	1148	1292	8.5	98.0	1.34	2.88	2.44	2.67	3.38	2.09	.86/.86
	L357	1.81	.64	.19	.10	.04	1061	1151	1289	8.5	97.0	1.27	2.10	2.23	2.26	2.46	2.33	.86/.86
	L358	1.79	.64	.19	.09	.04	1068	1152	1294	8.5	103.2	1.50	2.25	2.28	2.33	2.71	2.32	.86/.86
	L359	1.80	.64	.19	.10	.04	1067	1149	1296	7	82.2	1.01	1.68	2.33	2.33	2.49	2.18	.86/.86
	L360	1.80	.64	.19	.09	.04	1065	1149	1294	7	82.8	.97	1.70	1.89	2.05	2.33	2.16	--/--
	L361	1.80	.64	.19	.08	.04	1062	1151	1292	8	101.4	1.52	2.18	2.25	2.51	2.49	2.25	.86/.86
	L362	1.79	.64	.19	.09	.04	1058	1152	1293	7	78.4	.67	1.47	1.64	2.14	2.02	2.18	.87/.87
	L363	1.80	.64	.19	.11	.04	1056	1151	1295	7	85.3	.94	1.80	2.09	2.35	2.26	2.07	.86/.86
	L364	1.81	.64	.19	.10	.04	1060	1155	1289	8	94.1	1.13	1.96	2.35	2.51	3.13	2.72	.86/.86

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TABLE B-2
 (CRD) ZrC HED COATING RUNS ON NbC GEM BASECOATS (CRD)

Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Weight gms.	Thickness, mils						ZrC Lattice Parameters Sta. 49
	Ar	HCl	H ₂	SiH ₄	CH ₄	0"	26"	52"			4.5	13.5	22.5	31.5	40.5	49.5	
F404	2.08	---	.34	.03	---	1070	1345	1725	14	5.4	---	---	---	---	.26	.56	----
F405	2.09	---	.33	.04	---	1080	1350	1725	20	8.6	---	---	---	.21	.41	1.10	----
F406	2.12	---	.33	.04	---	1075	1350	1735	20	8.7	---	---	---	.16	.35	.80	----
F407	2.12	---	.33	.04	---	1090	1350	1720	20	8.3	---	---	---	.11	.18	.87	4.695
F408	2.12	---	.33	.04	---	1085	1355	1720	20	8.3	---	---	---	.12	.33	.85	4.698
F409	2.09	---	.33	.04	---	1095	1350	1720	20	8.4	---	---	---	.21	.37	.87	4.696
F424	2.19	---	.33	.03	---	1090	1355	1735	20	8.0	---	---	---	.18	.41	1.01	4.697
M148	2.16	---	.33	.03	---	1160	1345	1748	10	3.8	---	---	---	.21	.21	.58	4.698
M149	2.41	---	.33	.04	---	1100	1350	1745	20	8.5	---	---	---	.15	.37	.69	4.695
M150	2.42	---	.33	.03	---	1105	1350	1745	20	8.5	---	---	---	---	.33	.83	4.695
M151	2.46	---	.33	.04	---	1110	1351	1743	20	7.5	---	---	---	.11	.30	.69	4.696
M159	2.47	---	.33	.05	---	1116	1356	1752	20	7.2	---	---	---	.11	.39	.94	4.701
M164	2.39	---	.33	.04	---	1094	1355	1755	20	7.7	---	---	---	---	.35	.81	4.695
M165	2.47	---	.33	.04	---	1091	1351	1748	20	7.9	---	---	---	.11	.28	1.12	4.700
M166	2.42	---	.33	.04	---	1109	1360	1749	20	6.7	---	---	---	.12	.35	.87	4.698
M167	2.43	---	.33	.04	---	1105	1354	1750	20	7.5	---	---	---	.11	.26	1.17	4.698
M169	2.39	---	.33	.05	---	1101	1348	1753	20	7.0	---	---	---	.12	.35	.76	4.695
M170	2.39	---	.33	.05	---	1122	1356	1754	20	8.2	---	---	---	.13	.39	1.01	4.696
M173	2.38	---	.33	.04	---	1106	1350	1764	20	7.2	---	---	---	---	.37	.99	4.696
M174	2.39	---	.33	.05	---	1127	1351	1753	20	7.7	---	---	---	---	.44	1.22	4.699
M175	2.37	---	.33	.04	---	1103	1350	1757	20	7.6	---	---	---	.14	.39	1.04	4.701
M177	2.38	---	.33	.05	---	1102	1351	1753	20	7.5	---	---	---	.14	.39	1.24	4.699
M178	2.39	---	.33	.04	---	1099	1356	1752	20	7.6	---	---	---	---	.44	1.13	4.700
M179	2.39	---	.33	.04	---	1121	1352	1753	20	7.2	---	---	---	---	.41	1.17	4.700
M180	2.41	---	.33	.04	---	1111	1350	1750	20	7.3	---	---	---	---	.41	1.08	4.699
M181	2.38	---	.33	.05	---	1109	1354	1752	20	7.6	---	---	---	---	.37	1.15	4.699
M182	2.45	---	.33	.04	---	1106	1349	1772	20	9.7	---	---	---	---	.44	1.52	4.700
M183	2.39	---	.33	.04	---	1116	1358	1762	20	9.5	---	---	---	---	.49	1.43	4.700
M184	2.39	---	.33	.04	---	1106	1355	1754	20	9.0	---	---	---	---	.46	1.49	4.700

TABLE B-3

(CRD) ZrC GEM COATING RUNS ON NbC GEM BASECOATS (CRD)

Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Weight gms.	Thickness, mils						ZrC Lattice Parameters	
	Ar	HCl	H ₂	Salt	CH ₄	0"	26"	52"			4.5	13.5	22.5	31.5	40.5	49.5	Sta. 22	Sta. 49
F410	2.65	---	.25	.04	.04	900	1000	1200	10	9.2	---	---	---	---	---	---	---	---
F411	2.65	---	.25	.04	.04	895	1000	1195	10	12.3	---	---	---	---	---	---	---	---
F412	2.65	---	.25	.04	.04	905	1050	1225	10	16.2	.10	.23	.21	.35	.74	1.50	---	4.704
F413	2.65	---	.25	.04	.04	905	1050	1225	10	14.5	---	.12	.17	.32	.80	1.15	---	4.702
F414	2.64	---	.25	.03	.04	900	1000	1190	5	7.1	.09	.06	.12	.30	.65	2.05	---	4.704
F415	2.64	---	.25	.03	.04	905	1056	1225	10	20.3	.08	.15	.19	.44	.88	1.63	---	4.700
F416	2.66	---	.25	.03	.04	905	1050	1225	10	13.6	.06	.12	.26	.30	.62	1.06	---	4.704
F417	2.64	---	.33	.03	.04	975	1140	1225	10	23.1	.23	.37	.71	.67	.88	.67	4.706	4.698
F418	2.66	---	.33	.03	.04	970	1140	1225	10	19.3	.18	.41	.55	.62	.71	---	4.704	4.698
F419	2.66	---	.25	.03	.04	910	1050	1230	10	18.3	.06	.16	.25	.37	.85	1.66	---	4.704
F420	2.65	---	.25	.04	.04	905	1050	1225	10	17.6	.08	.08	.19	.46	.76	1.20	---	4.701-2
F421	2.65	---	.25	.04	.04	900	1050	1185	10	14.1	.09	.16	.21	.41	.79	.83	---	4.704
F422	2.57	---	.25	.03	.04	900	1050	1180	10	11.9	.05	.09	.18	.28	.42	.53	---	4.701-4
M152	2.71	---	.33	.06	.02	885	1060	1175	10	10.8	.21	.16	.16	.19	.41	.62	---	4.704
M153	2.70	---	.33	.07	.02	900	1050	1180	10	9.7	.16	.06	.10	.16	.33	.65	---	4.704
M154	2.71	---	.33	.07	.02	885	1055	1175	10	8.0	.15	.07	.12	.23	.30	.46	---	4.703
M155	2.71	---	.33	.08	.02	895	1050	1175	10	8.9	.16	.25	.14	.21	.39	.67	---	4.701
M157	2.67	---	.33	.08	.02	994	1151	1280	7	22.4	.14	.32	.41	.56	.80	1.33	---	4.698
M158	2.68	---	.33	.09	.02	991	1148	1281	5	15.3	.16	.21	.30	.46	.56	.94	---	4.698
M160	2.71	---	.33	.08	.02	977	1148	1278	7	16.4	.12	.25	.33	.49	.58	.83	---	4.699
M162	2.69	---	.33	.11	.02	990	1152	1317	5	19.5	.18	.25	.30	.44	.79	1.33	4.703	4.698
M163	2.69	---	.33	.10	.02	992	1150	1327	7	25.0	.08	.28	.42	.69	.94	1.57	4.707	4.698
M168	2.74	---	.33	.06	.02	987	1149	1327	8	25.0	.21	.42	.58	.92	1.13	1.91	4.709	4.698

TABLE B-4
(CRD) ZrC GEM COATING RUNS ON GRAPHITE SUBSTRATES (U)

Run No.	Gas Flow, LPME					Temperature, °C			Time hrs.	Weight gms.	Thickness, mils						ZrC Lattice Parameters	
	Ar	HCl	H ₂	Sn	CH ₄	0"	26"	52"			4.5	13.5	22.5	31.5	40.5	49.5	Sta. 22	Sta. 49
T142	2.56	---	.33	.04	.04	980	1150	1275	20	61.5	.33	.76	1.12	1.34	1.33	---	4.707	4.698
T143	2.65	---	.33	.03	.06	980	1155	1280	20	51.1	.44	1.18	1.34	---	---	---	4.704	4.697
T144	2.47	---	.33	.05	.04	980	1150	1275	20	64.2	.42	.94	1.71	2.07	2.37	---	4.707	4.698
T145	2.38	---	.33	.07	.02	983	1151	1277	20	58.9	.23	.62	1.17	1.75	2.19	3.01	4.707	4.698
M161	2.73	---	.33	.06	.02	1077	1176	1323	20	72.9	1.03	1.33	1.42	1.52	2.37	4.50	4.704	4.697
F427	2.86	---	.33	.07	.02	1125	1225	1323	20	79.3	1.96	2.33	1.71	2.14	2.58	2.81	4.700	4.698
F429	2.83	---	.33	.06	.02	1116	1251	1344	25	100.4	1.91	2.90	2.33	2.90	3.54	2.09	4.699	4.697

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APPENDIX C
(CRD) CORROSION TEST DATA (U)

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TABLE C-1 (CRD)
COATING DEVELOPMENT EVALUATION GEM NbC (U)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2648	C419 550-2082104	TS 3006	D1.01	3 x 10 + 8.5	36.3		8.36	53	11.49	0	2.45	80	PH's, Broke at 50
1.3147	L349 630-1047628	SX5	R1.09	8.5	6.8	0	-	0	-	0	-		Lost DP
1.3150	355-1047960	AXM	R1.09	2 + 18 + 2 x 10 + 2	15.8	0	0.28	14	11.86	0	1.84		Lost Power After Cycle 2
1.3166	L350 630-1047635	SX5	R1.09	3 x 10 + 5.5	8.2	5	0.56	1	5.80	0	0.61		Lost DP
1.2976	L330/M156 550-47230	GLF	R1.09	5.1	1.9	0		0		0			Broke at 21" Mech.
1.2967	630-46940	GLF	R1.09	2 x 10 + 5 + 13	15.9	0		7		0			Shutdown 5.0-13.0 Cycle 3 and 4, Lost Seal and DP

TABLE C-2 (CRD)
 COATING DEVELOPMENT EVALUATION
 GEM NbC/HED ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2689	C412/F406/ AA190 550-2082019	TS 3003	R1.07	10 + 3.0	3.1			0		0		100	Abort, Chuck and Element Cracked.
1.2759	550-2081203	TS 3003	R1.07	3 x 10 + 6.5	8.8			5		2		100	Abort, PH's
1.2794	550-2082009	TS 3003	R1.08	3 x 10 + 8.5	9.3			0		0		100	Abort, Seal Failed, Lost DP.
1.2827	550-2082002	TS 3003	R1.09	5 x 10 + 5.0	22.5			3		1		100	Abort, PH's
1.2683	C413/F406/ AA190 550-1046162	TS 3005	R1.07	1.6	2.2			1		0		85	Hot End Cracks
1.2777	550-1046172	TS 3005	R1.08	4 x 10 + 7.1 + 12.9	9.2			0		0		98	Chuck Failure
1.2785	550-1046170	TS 3005	R1.08	2 x 10 + 2.0	3.9			0		0		85	BAR Corroded, Lost DP
1.2899	550-1046174	TS 3005	R1.09	3 x 10 + 1.1	20.5			7		5		82	PH's, Lost DP
1.2694	C413/F408/ AA191 550-1046184	TS 3005	D1.01	6 x 10	7.3		0.48	0	2.54	5	3.48	60	
1.2901	550-1046186	TS 3005	R1.09	4 x 10 + 3.5	18.0			0		0		30	
1.2693	C413/F409/ AA191 550-2082036	TS 3003	R1.07	1.5 + 8.5 + 2 x 10 + 1.3	7.1		3.83	0	2.28	0	0.09	90	Hot End Crack
1.2903	550-1046142	TS 3003	R1.09	4 x 10	11.9		4.90		5.60		0.71		

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TABLE C-2 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2670	C415/F407/ AA190	TS 3005	R1.07	4 x 10	7.7		1.09	0	4.74	3	1.57	95	Hot End Cracks
1.2687	550-1046200	TS 3003	D1.01	2 x 10 + 6.0	5.9		1.69	10	3.56	0	0.00	100	Hot End Cracks
1.2690	550-2081985	TS 3003	R1.07	4.0	2.1		0.50	0	1.46	0	0.10	100	Hot End Cracks
1.2699	550-2081984	TS 3003	R1.07	6 x 10 + 3.8	20.4		4.71	2	11.90	13	3.69	80	Lost DP, Broke 17.8
1.2703	550-1046206	TS 3005	R1.07	4 x 10 + 1.6	10.8		1.21	14	6.10	0	3.39	80	PH's, Lost DP
1.2900	550-1046204	TS 3005	R1.07	10 + 5 + 15 + 10 + 6.2	21.4		5.87	2	11.69	0	1.34	100	PH's, Broke 47.6
1.2691	550-2082010	TS 3003	R1.09										
1.2692	550-2082024	TS 3003	R1.07	4 x 10	9.5		3.89	2	5.42	0	0.10	100	Hot End Cracks
1.2702	550-1046148	TS 3005	R1.07	9.5	5.7		0.94	0	3.24	2	0.92	100	PH's and Hot End Cracks
1.2713	550-2082025	TS 3005	R1.07	6 x 10 + 3.5	28.6		7.15	23	10.49	8	10.86	0	PH's, Lost DP
1.2902	550-1046154	TS 3005	R1.07	2 x 10 + 7.0	16.9		-	1	-	7	-	100	Surface Corrosion, Test Out of Spec.
1.2698	550-2082030	TS 3003	R1.09	3 x 10	10.2		2.71	1	4.10	0	0.89	100	
1.2698	C415/F409/ AA 191	TS 3005	R1.07	1.0 + 9.0 + 3 x 10	13.6		1.30	0	3.59	0	6.81	20	Hot End Cracks
1.2704	550-1046202	TS 3005	R1.07	6 x 10 + 5.0	19.4		4.40	0	8.28	0	2.42	18	BAR Corroded
1.2779	550-2081992	TS 3003	R1.08	10	9.6		-	0	-	2	-	100	Break at 28

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TABLE C-2 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2663	C417/F406/ AA190	GLF	R1.07	4 x 10 + 1.6	7.3		1.69	0	4.80	1	0.01	80	Mech. Break 51.6
1.2665	550-1046443	GLF	R1.07	5 x 10 + 8.0	19.6		2.87	0	7.05	0	9.58	75	Mech. Break 51.0
1.2669	C417/F407/ AA190	GLF	R1.07	6 x 10	10.8		3.17	0	6.51	0	0.52	80	Hot End Cracks
1.2686	550-1046454	GLF	R1.07	8 x 10	15.8		3.31	1	11.25	4	1.24	95	Mech. Break at 51
1.2684	C417/F408/ AA191	GLF	R1.07	4 x 10	8.2		2.22	0	4.15	1	1.83	92	Hot End Cracks
1.2714	550-1046457	GLF	R1.07	10 + 5.0	5.8		-	0	-	3	-	90	PH's, Lost DP
1.2688	C417/F409/ AA191	GLF	R1.07	3 x 10 + 1.4	8.7		1.54	0	3.66	5	3.58	87	Corr. Break 51
1.2715	550-1046467	GLF	R1.07	4 x 10 + 3.5	7.8		4.52	0	6.77	0	0.00	90	Fce. Seal Leak
1.2732	550-1046472	GLF	R1.07	8.0	4.6		-	0	-	0	-	90	Corr. Break 48.5 (Re-Test)
1.2932	C439/M150/ AA200	GLF	R1.09	10	8.6		0.88	0	8.82	0	0.00		Broke 48 Corr.
1.2948	431-2081948	AXZ	R1.09	2 x 10 + 8.3	12.7		-	0	-	0	-		Bowed and Broke at 47
1.2949	550-1046753	GLF	R1.09	10 + 0.5	5.5		0.94	3	4.39	0	-		PH's, Lost DP
1.2972	431-2081950	II Ga	R1.09	10	6.0		0.16	0	3.62	0	0.12		Broke - 48 Corr.

TABLE C-2 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2991	550-1046754	GLF	R1.09	3 × 10 + 0.1	11.5		1.95	0	9.05	0	0.50		PH's, Lost DP
1.3010	550-1046433	M3	R1.09	10 + 9.5 + 10.5 + 3 × 10	19.3		4.70	4	15.94	0	1.16		PH's, Lost DP
1.3098	550-1046488	M3	R1.09	3 × 10 + 5.0	18.5		0.93	9	14.75	0	0.64		Surface Corrosion
1.2973	C441/M150/ AA200	GLF	R1.09	10 + 3.5	11.2	0	0.91	6	11.28	0	0.11		Lost DP
1.2942	630-1047196	GLF	R1.09	10 + 0.1	12.2	0	0.60	4	10.53	0	0.15		Broke 45 Corr.
1.3107	630-1047190	SX5	R1.09	6.8	4.5	0	-	0	-	0	-		Broke 43 Arcing
1.3112	550-1046629	M3	R1.09	10 + 0.5 + 4.0	5.5	0	0.19	4	4.60	0	0.27		Lost Seal

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TABLE C-3 (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2617	C409/F404 550-1046126	GLF	D1.01	3 x 10 + 9.9	25.3			22		0		78	Abort, PH's, Broke 30.5
1.2618	550-1046178	GLF	R1.07	2 x 10 + 4.8	17.3			14		0		80	Abort, PH's, Broke 26.8
1.2623	550-1046130	GLF	D1.01	3 x 10 + 6.2	25.3			49		0		75	Abort, PH's, Broke 30.6
1.2624	550-1046190	GLF	R1.07	2 x 10 + 5.0	23.1			16		1		85	Abort, PH's, Broke 25.5
1.2649	C413/F405 550-2082016	TS 3003	D1.01	6 x 10	10.3		5.94	33	3.31	1	0.75	100	Hot End Cracks
1.2650	550-1046180	TS 3005	D1.01	5 + 15 + 4 x 10	7.1		1.54	0	2.06	0	3.20	80	Hot End Cracks
1.2651	550-1046182	TS 3005	R1.07	3 x 10	7.0		1.65	0	3.50	6	0.85	99	Abort, Furnace Problem
1.2652	550-2082034	TS 3003	R1.07	2 x 10	3.7		1.70	0	1.40	2	0.00	92	PH's, Hot End Crack
1.2658	C417/F406 550-1046429	GLF	R1.07	4 x 10	5.5		1.27	0	4.31	2	0.02	90	Hot End Cracks
1.2659	C417/F407 550-1046446	GLF	R1.07	4 x 10	6.5		1.81	0	4.19	0	0.50	75	Hot End Cracks
1.2737	C417/F408 550-1046460	GLF	R1.07	2 x 10 + 3.1	3.2		0.59	0	2.61	0	0.00	78	Corr. Hole 31
1.2738	C417/F409 550-1046475	GLF	R1.07	3 x 10 + 4.7 + 10 + 9.0	11.5		4.93	0	6.50	5	0.00	85	Broke at 51
1.2745	C419/F408 550-2082099	TS 3006	D1.01	4 x 10 + 7.7	22.9		8.92	20	6.17	27	0.00	80	Broke at 51
1.2927	C439/M150 431-2081934	II Ga	R1.09	2 x 10 + 9.3	15.0		-	0	-	0	-	0	BAR Corr. 1/2 In. Back
1.2930	550-1046737	GLF	R1.09	10 + 4.0	6.1		0.30	0	3.84	5	0.16	99	Corr. Hole 48

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TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2928 1.3114	C441/M150 630-1047140 550-1046627	SX5 M3	R1.09 R1.09	2 x 10 + 4.0 4 x 10 + 5 + 15	5.2 11.0	0 0	1.11 0.91	0 1	3.09 7.69	2 1	2.92 0.49		Arcing 51 Lost Seal
1.2960 1.2961	L328/M151 630-47168 243-47486	SX5 AXM	R1.09 R1.09	2 x 10 + 3.5 + 16.5 + 3.5 2 x 10 + 1.0 + 19 + 1.7	9.6 13.0	0 0	2.82 1.14	8 6	4.67 7.82	0 0	0.88 0.44		Shutdown 3.5 Cycle 3 and 5, Lost Seal and DP Shutdown 1.0 and 1.7 Cycle 3 and 5, Lost Seal and DP
1.2963	630-47162	SX5	R1.09	2.0	4.3	0	2.46	0	5.34	1	4.79		Broke 51-5/8, Corr. Pocket in Non-Fuel Trans.
1.2938 1.2940	630-47167 243-47483	SX5 AXM	R1.09 R1.09	3 x 10 + 0.1 + 6.0 4.2 + 6.0 + 19.8 + 2 x 10 + 8	7.2 7.8	0 0	1.75 1.07	9 1	3.67 3.41	0 0	1.12 0.56		Shutdown 6.0, Lost DP Large Hole at 29-1/2"
1.2921 1.2922	630-47162 243-47480	SX5 AXM	R1.09 R1.09	3.8 + 4.3 + 21.9 + 10 + 3.3 3 x 10 + 5.5 + 14.5 + 10	8.1 14.7	0 0	2.46 1.35	0 0	5.34 9.05	0 4	4.79 0.59		Chuck Failed at 48-3/4, 49-1/4
1.3023	C432/M159 550-46655	M3	R1.09	2 x 10 + 8.5 + 11.5 + 2 x 10	22.3	0	1.80	3	16.96	0	1.46		

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TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3040	550-46654	M3	R1.09	6 + 14 + 10 + 6.4 + 13.6 + 10	19.2	0	1.24	10	15.22	0	0.73		
1.3035	C437/M150/ M159 431-47060	AXZ	R1.09	2 x 10 + 3.0	8.0	0	0.56	127	4.91	0	0.37		Lost DP, Pinhole Surface
1.3064	413-47059	AXZ	R1.09	3 x 10	10.9	6	0.98	0	6.17	0	0.62		Corr. 40 to 49-1/2 Broke at 21-1/2
1.3021	C438/M149/ M159 431-81935	II Ga	R1.09	3 x 10	17.6	0	0.24	0	4.57	0	0.22		Bar Corr. to 1" Back
1.3025	431-81929	II Ga	R1.09	10 + 1.0	4.7	0	0.21	0	1.52	0	0.06		Bar Corr. to 1/4" Back
1.3038	431-81943	II Ga	R1.09	2 x 10 + 8.0	17.0	0	0.56	0	4.87	0	0.29		Lost DP, Bar Corr. to 1" Back
1.3019	C439/M150/ M159 550-46749	GLF	R1.09	2 x 10 + 8 + 12 + 2 x 10	22.0	0	1.98	3	16.04	0	1.38		
1.3020	550-46428	M3	R1.09	2 x 10 + 8 + 12 + 2 x 10	20.5	0	2.29	2	15.05	0	1.15		Bow from 27" to 40"
1.3027	431-81941	II Ga	R1.09	2 x 10 + 9.0	16.0	0	0.42	0	9.08	0	0.50		Bar Corr. to 1/16 Back, Lost DP
1.3088	550-46424	M3	R1.09	5 x 10 + 8.8	17.2	0	1.99	7	13.03	2	0.81		Shutdown, Lost DP
1.3099	550-46738	GLF	R1.09	3 x 10 + 8.5 + 11.5 + 10	26.5	0	1.83	59	20.02	0	0.98		Lost Seal 8.5 Cycle 4, Broke 30-3/4 Corr.

TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3026	C441/M150/ M159 630-47146	SX5	R1.09	10 + 5.0 + 15 + 10 + 6.0	9.6	0	0.62	0	5.79	5	1.59		Abort, PH's Lost DP
1.3034	630-47144	SX5	R1.09	10 + 8.5 + 11.5 + 10 + 7.0	14.2	0	0.80	85	10.37	0	1.25		Broke 48" on Ramp to Cycle 6
1.3029	L332/M159 630-46900	GLF	R1.09	10 + 2.4	7.8	0	0.16	16	6.49	0	0.10		Abort PH's, Lost DP
1.3036	630-46901	GLF	R1.09	8.5 + 11.5 + 7.5 + 12.5 + 2 x 10	21.5	0	0.76	51	15.14	0	2.44		Lost Seal 8.5 Cycle 1 and 7.5 Cycle 3
1.3047	630-46902	GLF	R1.09	10	7.9	0	-	18	-	0	-		Shutdown, Lost DP
1.3065	630-46949	GLF	R1.09	5 + 15 + 10 + 5.2 + 14.8 + 7.4	21.5	0	0.56	25	19.67	0	0.10		Lost DP 7.4 Cycle 6
1.3032	L333/M159 630-46861	GLF	R1.09	2 x 10 + 4 + 16 + 7.3 + 12.7	20.6	0	0.78	89	14.73	0	1.21		
1.3042	630-46865	GLF	R1.09	2 x 10 + 4.0 + 10.5	8.0	0	0.53	0	5.82	1	0.27		Lost DP 10.5 Cycle 4
1.3060	630-46866	GLF	R1.09	10 + 9.0	5.0	0	0.26	7	3.54	0	0.11		Shutdown, Lost DP
1.3087	630-46867	GLF	R1.09	10 + 6.3	6.5	0	0.25	10	5.91	0	0.08		Lost DP
1.3101	L343/M164 630-48095	AXF	R1.09	2 x 10 + 4.0 + 16 + 1.5	9.6	0	0.78	2	6.58	0	1.11		Shutdown 1.5 Cycle 5, Lost DP
1.3100	630-47948	AXM	R1.09	2 x 10	9.3	0	0.78	0	5.76	3	0.72		Shutdown, Lost DP, Surface Corr. 30 to 49-3/8

TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3104	630-47950	AXM	R1.09	3 x 10 + 3 + 17 + 10	13.8	0	1.17	0	10.68	0	1.21		Lost Seal 3' Cycle 4
1.3105	630-48098	AXF	R1.09	3 x 10 + 4 + 8.5	12.0	0	0.96	0	9.02	1	1.27		Broke at 48-1/4, Corr. Pocket
1.3122	630-47518+	AXM	R1.09	3 x 10 + 3 + 17 + 3.5	22.7	0	0.57	0	8.56	0	13.07		Lost Seal 3' Cycle 4
1.3123	630-47518	AXM	R1.09	5 x 10 + 1.0	19.4	5	0.41	0	6.44	0	12.32		Shutdown, Lost DP
1.3126	400-48029	AXF	R1.09	5 x 10 + 4.5	10.4	0	0.23	0	7.97	0	0.57		Shutdown, Lost DP, Cold Break at 51
1.3127	550-46752	GLFI	R1.09	3 x 10 + 9.5 + 10.5 + 10	13.2	0	1.52	0	10.23	0	0.68		Lost Seal 9.5 Cycle 4
1.3132	630-47519	AXM	R1.09	3 x 10 + 8.5 + 11	9.4	0	0.53	0	6.57	2	2.62		Lost Seal 8.5 Cycle 4
1.3133	630-47517	AXM	D1.01	6 x 20 + 0.1	7.3	101	1.21	40	3.37	21	1.67		Mech. Break 4-3/4 and 48-1/2, Trans. Crack 49-3/4
1.3134	630-47516	AXM	R1.09	4 x 10 + 2	7.3	0	0.58	0	4.66	4	1.25		Abort, PH's, Lost DP
1.3137	630-47521	AXM	D1.01	5 x 20 + 11	6.1	0	0.43	0	3.26	3	2.23		Abort, Lost DP, Crack at 50
1.3138	630-48032	AXF	D1.01	5 x 20 + 7 + 4	11.0	0	0.32	6	5.41	11	0.67		Broke at 49, Cracks 49 to 51
1.3171	630-48099	AXF	A6.05	2 x 18 + 2 x 10 + 5 + 2	5.4	0	0.47	0	3.67	0	0.61		Lost DP, 2 Cycle
1.3172	400-48031	AXF	A6.05	7 + 13 + 4 x 10	6.8	0	0.23	0	5.27	0	0.82		Graphite Ring Broke 7" Cycle 1
1.3185	630-48100	AXF	A6.06	6 x 10	4.7	0	1.74	0	3.26	0	0.80		BAR Corners Chipped

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TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3158	L346/M166 521-47936	AXM	R1.09	1 + 19 + 8 + 12 + 1	6.3	0	0.10	0	4.89	0	0.58		Shutdown 8' Cycle 3, Lost Seal
1.3162	630-47524	AXM	R1.09	5 x 10 + 1.0	14.6	0	0.62	6	9.47	2	0.76		Lost DP, Seal Mark at 51-3/4
1.3163	630-47617	SX5	R1.09	3 x 10 + 6.0 + 5.0	8.4	0	0.34	0	4.30	0	3.03		Shutdown, Lost Seal 6" Cycle 4
1.3168	521-47926	AXM	R1.09	2 x 10 + 9.6	4.7	0	0.30	0	2.25	0	0.23		Lost DP, Broke at 51" Joint
1.3179	630-47529	AXM	A6.05	3 x 10 + 4.0 + 1.5 + 24.5	7.2	0	0.73	0	6.16	0	1.32		Lost Seal 4.0 Cycle
1.3186	431-47978	AXM	A6.06	5 x 10 + 6.5	5.4	0	1.05	0	4.57	0	0.54		Shutdown, Lost DP
1.3190	267-47910	AXM	A6.06	6.0 + 1.5 + 8.0	2.0	0	1.06	0	1.49	0	0.45		Chuck Failed 6' Cycle 1
1.3196	630-47526	AXM	A6.06	3 x 10 + 0.5	2.2	0	0.76	0	1.34	1	0.10		Lost DP, Seal Mark at 50-3/4
1.3231	293-47912	AXM	A6.06	3 x 10 + 1 + 19 + 10	5.2	0	0.79	0	4.54	0	0.22		Rechucked 1' Cycle 4
1.3264	267-47911	AXM	A6.07	6 x 10	13.2	0	0.67	2	11.73	0	0.64		
1.3288	630-47618	SX5	A6.07	6 x 10	11.7	0	0.20	0	5.83	1	5.73		
1.3183	L345/M167 630-1048103	AXF	R1.09	3 x 10 + 5.0	4.6	2	0.98	0	4.02	0	0.26		Shutdown, Lost DP
1.3199	630-1048104	AXF	R1.09	4 x 10 + 6.5	7.0	0	-	0	-	1	-		Lost DP, Large PH at 51-1/4
1.3286	630-1047105	AXF	A6.07	6 x 10	5.4	0	1.06	0	3.85	1	0.54		

TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3167	L347/M167 630-47602	SX5	R1.09	3 x 10 + 2.0	14.0	0	0.42	0	9.98	0	0.98		Lost DP, Trans. Crack at 51
1.3173	267-47904	AXM	R1.09	10 + 5.8 + 14.2 + 2 x 10	13.8	0	1.16	18	10.65	0	0.95		Lost Seal 5.8 Cycle 2
1.3174	400-48038	AXF	R1.09	10 + 6.0	6.5	0	1.05	0	4.50	0	0.50		Shutdown, Lost DP
1.3175	400-48079	AXF	R1.09	3 x 10 + 1.0 + 4.0	6.3	0	0.86	0	5.43	5	1.25		Lost DP, Lost Seal 1 Cycle 4
1.3176	521-47919	AXM	R1.09	10 + 8.5	5.5	0	0.97	0	4.32	0	0.39		Lost DP
1.3177	630-47527	AXM	R1.09	3 X 10 + 3.5 + 5.0	8.2	0	0.89	0	5.34	3	1.93		Lost Seal 3.5 Cycle 4, Lost DP
1.3178	293-47916	AXM	R1.09	2 x 10 + 1.5 + 18.5 + 2 x 10	11.7	0	0.42	0	8.35	0	1.05		Lost Seal 1.5 Cycle 3
1.3181	521-47920	AXM	A6.05	6 x 10	6.1	0	0.99	0	3.90	1	0.97		Transverse Crack at 49-1/2
1.3182	630-47606	SX5	R1.09	60	8.9	0	0.74	0	6.76	0	0.42		Seal Mark 51-3/4 to 1/4" Bow Up
1.3184	630-47607	SX5	R1.09	3 x 10 + 1.5 + 18.5 + 0.2	17.8	0	1.61	2	11.81	0	0.68		Lost Seal, 1.5 Cycle 4
1.3187	400-48039	AXF	R1.09	3 x 10 + 2.0	5.1	0	1.35	0	3.84	0	1.31		Shutdown, Lost DP
1.3188	400-48080	AXF	R1.09	2 x 10 + 1.0 + 19.0 + 2 x 10	10.0	0	0.94	0	7.37	8	1.90		Lost Seal 1.0 Cycle 3
1.3189	630-47047	AXF	R1.09	3 x 10 + 0.0 + 16.0	8.5	0	1.08	0	5.40	1	1.58		Lost Seal On Ramp to Cycle 4

TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3191	630-47528	AXM	A6.06	2 x 10 + 1.0	1.4	0	1.25	0	2.06	0	0.43		Lost DP 1.0 Cycle 3
1.3195	293-47917	AXM	A6.06	2 x 10 + 2.0	2.2	0	1.15	0	3.28	0	0.43		Broke 49-1/4
1.3197	630-47608	SX5	R1.09	5.5 + 14.5 + 1 + 19	6.2	0	1.60	0	5.23	0	0.78		Lost DP 19' Cycle 4
1.3203	267-47905	AXM	A6.06	6 x 10	6.4	0	0.80	0	4.92	3	0.62		Shutdown, Lost DP
1.3207	630-47609	SX5	A6.06	3 x 10 + 4	4.6	0	0.50	1	3.19	0	0.59		Broke at 49-1/4 Arcing
1.3211	400-48081	AXF	A6.06	1.0	3.0	0	-	0	-	0	-		Corr.
1.3212	400-48082	AXF	R1.09	4 x 10 + 1	6.0	0	0.45	0	4.44	2	1.15		Shutdown, Lost DP
1.3230	521-47921	AXM	A6.06	3 x 10 + 1.5 + 18.5	6.0	0	0.66	0	3.82	0	1.21		Rechuck 1.5, Lost Seal
1.3263	267-1047906	AXM	A6.07	6 x 10	13.1	1	0.39	59	11.10	0	1.12		Surface Corr. from 29-1/2 to 48-1/2
1.3277	400-1048040	AXF	A6.07	6 x 10	4.3	0	0.73	0	2.99	0	0.32		
1.3278	630-1047604	SX5	A6.07	6 x 10	9.5	0	0.86	0	8.23	0	0.48		
1.3287	630-1047603	SX5	A6.07	6 x 10	9.0	0	1.35	0	3.84	0	1.31		
1.3192	L345/M169 630-1047952	AXM	R1.09	4 x 10 + 1.5	8.4	0	1.41	0	6.58	14	1.27		Lost DP, BAR Chipped Pre-Test
1.3204	630-1047530	AXM	R1.09	4 x 10 + 1.5 + 14.0	15.8	0	1.43	0	9.88	6	2.79		Rechucked 1.5 of 5th Cycle
1.3206	400-1048033	AXF	R1.09	10 + 2.5 + 8.5	6.8	0	1.88	0	3.73	3	0.32		Shutdown 8.5, Lost DP
1.3226	550-1046755	GLF	R1.09	5 x 10 + 2	11.9	0	1.26	3	9.86	0	0.63		Lost DP 2' Cycle 6
1.3228	630-1047532	AXM	R1.09	10 + 1.5 + 18.5 + 2 x 10 + 1	12.3	0	1.63	2	7.05	3	3.01		Rechucked 1.5 Cycle 2 Washer Corr.

TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3229	400-1048034	AXF	R1.09	1 + 19 + 1.5 + 18.5 + 10 + 2	12.3	0	1.16	12	10.34	0	0.71		Lost DP 2' Cycle 6, PH
1.3233	630-1047533	AXM	A6.06	6 x 10	6.7	0	0.20	0	2.58	1	1.88		
1.3234	400-1048035	AXF	A6.06	6 x 10	5.8	0	0.63	0	4.02	0	0.55		
1.3235	400-1048037	AXF	A6.06	6 x 10	5.9	0	0.41	0	2.45	0	0.70		
1.3193	L348/M169 200-1047892	AXM	R1.09	3 x 10 + 1.5	7.8	0	0.82	8	6.04		1.30		Lost DP, Corr. Pocket 51-1/4 to 51-5/8
1.3194	166-1047886	AXM	A6.06	4.5	0.0	0	-	0	-		-		Lost DP, Trans. Crack 49-1/4
1.3201	630-1047613	SX5	R1.09	5 + 5.5	3.1	0	0.26	0	2.17	0	1.51		Lost Seal 5.0, Mech. Break 51
1.3205	400-1048087	AXF	R1.09	2 x 10 + 5.0	6.0	0	0.82	0	3.97	0	0.57		Loss ΔP, Seal Failed
1.3218	630-1047621	SX5	R1.09	2 x 10 + 1 + 19 + 10 + 3.5	14.1	0	1.51	0	9.23	6	3.76		Lost DP 3.5 Cycle 6, Pinholes
1.3225	355-1047961	AXM	R1.09	3 x 10 + 6.8 + 2	7.7	0	0.48	3	5.41	2	1.80		Lost DP 2' Cycle 5
1.3227	630-1047614	SX5	R1.09	1.8 + 18.2 + 10 + 3.5	8.1	0	1.53	0	5.68	2	0.73		Rechucked 1.8 Cycle 1
1.3232	391-1047972	AXM	R1.09	2 x 10 + 1 + 19 + 1.5	7.9	0	0.09	0	3.74	3	1.85		Lost DP 1.5 Cycle 5
1.3269	630-1047915	SX5	A6.07	6 x 10	10.4	0	1.79	0	6.79	0	2.07		Coat Flaking 51-52
1.3270	630-1048088	AXF	A6.07	6 x 10	8.0	0	1.06	0	6.30	2	0.77		Blistering 48-3/4 to 49
1.3284	630-1047616	SX5	R1.09	5 x 10	15.0	0	1.34	0	10.10	0	3.69		Broke at 51 - Corr.

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TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3200	L349/M169 630-1047629	SX5	A6.06	5 x 10 + 1.5	3.9	0	1.29	0	3.65	0	0.49		Lost DP 1.5, Cracks 51 to 51-3/8 Mech. Break 50-1/4 unloading Shutdown, Lost DP
1.3202	391-1047971	AXM	A6.06	6 x 10	3.5	0	0.53	0	2.35	0	0.72		
1.3222	200-1047890	AXM	R1.09	5 x 10 + 1.0	8.8	0	0.63	14	5.55	6	2.41		
1.3221	L350/M169 166-1047885	AXM	R1.09	3 x 10 + 3 + 17 + 10	8.9	0	1.33	0	7.07	0	0.50		Rechucked 3' Cycle 4, Corr. Rechucked at 1.8 Cycle 5
1.3223	200-1047887	AXM	R1.09	4 x 10 + 1.8 + 18.2	8.1	0	1.63	0	6.13	0	0.54		
1.3236	L351/M170 573-1047941	AXM	A6.06	5 x 10 + 1	3.0	0	0.73	0	1.27	0	0.23		Lost DP, Seal Corroded Lost DP, Seal Corroded Rechuck 7.3 Cycle 5, Washer Corr. Lost DP, Stop Corrosion
1.3237	267-1047899	AXM	R1.09	5 x 10 + 4.5	7.7	0	0.75	0	6.83	0	0.46		
1.3238	630-1047636	SX5	A6.06	4 x 10 + 7.3 + 12.7	3.4	0	1.47	0	1.11	0	0.42		
1.3276	243-1047896	AXM	A6.07	5 x 10 + 7 x 10	20.0	0	1.42	0	10.10	3	7.07		
1.3282	630-1047637	SX5	A6.07	7 x 10 + 6.3	7.0	0	1.13	0	5.46	0	0.49		
1.3246	L352/M175 243-1047897	AXM	A6.06	6 x 10	4.5	0	0.33	0	3.50	0	0.44		
1.3247	630-1047638	SX5	A6.06	6 x 10	3.9	0	0.99	0	2.79	0	0.31		
1.3261	630-1047643	SX5	R1.09	4 x 10 + 8	10.4	0	1.84	0	8.14	4	0.59		
1.3279	630-1047639	SX5	A6.07	6 x 10	4.7	0	0.88	0	3.35	1	0.31		

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TABLE C-3 (CONT.) (CRD)
 COATING DEVELOPMENT EVALUATION
 GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3248	L354/M175 630-1047644	SX5	A6.06	6 x 10	5.2	0	1.15	0	3.48	2	0.35		Shutdown, Lost DP Blistering at 48-1/2 to 49
1.3249	391-1047962	AXM	A6.06	6 x 10	7.4	0	0.76	0	6.31	3	0.44		
1.3262	630-1047645	SX5	R1.09	4 x 10 + 2.2	20.6	1	1.22	2	7.17	0	8.12		
1.3280	630-1047647	SX5	A6.07	6 x 10	8.7	0	1.26	0	6.76	3	0.87		
1.3289	630-1047649	SX5	A6.07	5 x 10 + 4.5	9.9	0	1.15	4	3.48	3	0.64		
1.3242	L355/M175 166-1048545	GLFI	R1.09	5 x 10 + 4.5	10.6	0	0.29	0	6.76	0	0.55		Lost DP 4.5 Cycle 6, Spacer Corr. Lost DP 3.5 Cycle 6, Spacer Corr. Lost DP 6.8 Cycle 6
1.3243	166-1048547	GLFI	R1.09	5 x 10 + 3.5	10.7	0	0.15	3	6.28	0	0.70		
1.3244	166-1048548	GLFI	R1.09	6 x 10	14.8	0	1.79	0	12.00	2	0.79		
1.3245	630-1047701	SX5	A6.06	6 x 10	4.5	0	0.95	0	2.23	1	1.61		
1.3260	430-1047975	AXM	A6.07	6 x 10	5.9	0	0.81	0	4.67	0	0.83		
1.3265	630-1047702	SX5	R1.09	3 x 10 + 1 + 19 + 6.8	10.8	0	1.37	1	10.22	0	14.41		Broke on Ramp at 48-1/4
1.3267	166-1048551	GLFI	A6.07	6 x 10	7.7	0	0.94	0	6.27	0	0.49		
1.3268	166-1048554	GLFI	A6.07	6 x 10	7.5	0	1.07	0	5.89	2	0.42		
1.3275	430-1047975	AXM	A6.07	10	2.7	0	0.99	0	6.69	1	0.56		
1.3281	630-1047699	SX5	A6.07	6 x 10	6.6	0	1.06	0	5.20	0	0.56		
1.3290	630-1047700	SX5	A6.07	6 x 10	8.1	0	0.67	0	6.17	1	1.03		
1.3250	L357/M177 166-1048543	GLFI	A6.07	6 x 10	6.2	0	1.12	0	4.97	0	0.41		

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TABLE C-3 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/HED ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3251	166-1048549	GLFI	R1.09	5 x 10 + 4.5	12.4	0	1.18	0	10.32	0	0.91		Lost DP 4.5 Cycle 6
1.3255	166-1048546	GLFI	A6.07	6 x 10	4.7	0	0.89	0	3.43	0	0.31		
1.3257	166-1048553	GLFI	R1.09	3 x 10 + 9 + 11 + 10	15.2	0	1.99	0	10.25	0	2.93		Rechuck 9' Cycle 4
1.3266	166-1048539	GLFI	A6.07	10 x 10	32.7	0	1.88	2	27.74	13	1.81		Broke on Ramp to Cycle 11
(Retest) 1.3273	166-1048546	GLFI	A6.07	6 x 10	21.9	0	2.70	50	18.58	24	3.80		Broke at 48-1/4 Unloading
1.3283	166-1047542	GLFI	A6.07	6 x 10 + 7.5	18.7	0	1.92	0	6.83	0	10.27		Total Corrosion 50-3/4 to 51-5/8
1.3253	L358/M177 166-1048558	GLFI	A6.07	6 x 10	4.8	0	0.55	0	3.79	0	0.34		Lost DP, Spacers and Stop Corroded
1.3254	166-1048544	GLFI	R1.09	5 x 10 + 2.5	9.6	0	1.29	0	7.12	0	0.57		
1.3258	166-1048560	GLFI	A6.07	6 x 10	5.6	0	1.20	0	3.91	0	0.37		Shutdown, Lost DP
1.3259	166-1048556	GLFI	R1.09	5 x 10 + 1.0	12.4	0	1.17	0	10.52	0	0.83		
(Retest) 1.3274	166-1048560	GLFI	A6.07	3 x 10	9.0	1	2.07	15	9.36	18	1.47		Broke at 48-3/4, Corr. Around Bores
1.3285	166-1048562	GLFI	A6.07	7 x 10 + 3 x 10	17.8	0	2.24	25	12.30	13	2.76		Rechucked After 7 x 10

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TABLE C-4 (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2757	C410/F411/ F414/AA193 550-1046194	TS 3005	R1.07	3 x 10 + 4.5	8.3		3.21	5	6.22	1	0.57	95	Abort, PH's
1.2751	C412/F410/ F414/AA193 550-208003	TS 3003	R1.07	5.5	1.0	0	1.22	0	1.13	0	0.05	100	Abort, Cracks
1.2756	C412/F411/ F414/AA193 550-2081989	TS 3003	R1.07	2 x 10 + 2.0	13.5			20		8		100	Abort, PH's
1.2793	550-2081995	TS 3003	R1.08	2 x 10	10.0		1.52	31	8.73	2	0.15	100	Break, Corr. Pocket
1.2752	C413/F410/ F414/AA193 550-1046132	TS 3005	R1.07	4 x 10	6.3		3.26	8	4.05	0	0.49	99	Hot End Cracks
1.2792	550-1046188	TS 3005	R1.08	2 x 10 + 8.0	4.0		1.81	0	2.94	0	0.35	99	Hot End Cracks
1.2755	C415/F410/ F414/AA194 550-2082020	TS 3003	R1.07	2 x 10 + 1.7	8.0		2.28	0	5.61	0	0.11	100	Hot End Cracks
1.2716	C422/C423/ F410/AA192 550-1046439	GLF	R1.07	9.5	1.8		-	0	-	0	-	95	Hot End Cracks
1.2720	550-1046540	M3	R1.07	4 x 10	8.5		-	4	-	0	-	99	Hot End Cracks
1.2887	550-1046697	M3	R1.08	10 + 1.2	11.7		-	4	-	0	-	100	PH's, Broke 48.8
1.2718	C422/C423/ F411/AA192 550-1046158	GLF	R1.07	4 x 10	4.9		-	9	-	0	-	90	Hot End Crack

TABLE C-4 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2723	630-1046698	M3	R1.07	2 x 10	6.3		-	0	-	0	-	100	Broke 51
1.2797	550-1046427	GLF	R1.08	2 x 10	6.3		-	10	-	1	-	100	PH's, Lost DP
1.2739	C422/C423/ F412/AA193	GLF	R1.07	10 + 2.0	7.5		0.35	22	4.98	6	1.97	80	Broke 48 & 51 w/Corr.
1.2748	550-1046442	GLF	R1.07	10 + 0.7	3.8		0.28	0	1.76	8	1.86	85	Broke 51 w/Corr.
1.2749	550-1046451	GLF	R1.07	10 + 1.8	3.0		1.08	0	1.85	0	0.07	98	Broke 51, Mech.
1.2760	C422/C423/ F413/AA193	GLF	R1.07	10 + 5.3	10.0		1.92	7	5.92	0	-	75	Broke 46 w/Corr.
1.2886	550-1046435	GLF	R1.07	8.0	3.0		1.74	1	3.99	0	0.27	100	PH's, Lost DP
1.2847	C421/C424/ F416/AA194	TS3006-1	R1.08	2 x 10 + 3.5	7.4		1.47	0	4.51	0	0.32	100	Cracks, Lost DP
1.2874	550-2082168	TS3006-1	R1.08	10 + 0.8	6.7		1.42	4	3.15	0	0.23	85	Broke 45.9, Arcing
1.2753	550-2082006	TS3006-2	R1.07	10 + 5.5	25.4		7.60	0	15.68	0	0.52	90	Corr. Break 48.6
1.2875	550-2082055	TS3006-2	R1.08	10 + 5.5	30.3		4.03	1	25.20	1	0.07	90	Corr. Break 48.5
1.2848	550-2082063	TS3006-3	R1.08	10 + 1.1	4.8		0.80	0	2.32	0	0.18	100	Hot End Cracks, Lost DP
1.2876	550-2082071	TS3006-3	R1.08	2 x 10 + 6.8	4.5		2.42	3	3.54	0	0.44	90	Lost DP
1.2849	550-2082066	TS3006-4	R1.08	2 x 10 + 0.1	7.3		0.84	19	6.17	0	0.09	98	Corr. Break 47.9.
1.2877	550-2082038	TS3006-4	R1.08	2 x 10 + 2.3	7.7		1.35	64	5.61	2	0.64	85	Corr. Break 46.6
1.2852	550-2082078	TS3006-5	R1.08	4 x 10	16.5		1.81	0	4.61	4	3.30	97	Hot End Cracks, Broke 51
1.2878	550-2082093	TS3006-5	R1.08	2 x 10 + 5.4	13.9		2.91	15	6.56	0	0.93	100	Hot End Cracks, Lost DP

TABLE C-4 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2853	550-2082103	TS3006-6	R1.08	2 x 10	5.6		1.10	0	3.92	2	0.28	95	Lost DP
1.2879	550-2082100	TS3006-6	R1.08	4 x 10	6.2		1.73	0	3.74	0	0.53	97	
1.2873	550-2082109	TS3006-7	R1.08	10 + 4.8	13.9		1.36	9	13.46	2	0.18	100	Lost DP
1.2883	550-2082113	TS3006-7	R1.08	10	5.2		1.20	0	2.67	0	0.03	95	Broke 46.75
1.2754	550-2082124	TS3006-8	R1.07	4 x 10	6.2		2.12	2	4.43	0	0.43	100	
1.2884	550-2082127	TS3006-8	R1.08	10 + 0.5	5.4		1.92	2	2.91	0	0.17	90	Broke 46.9
1.2767	550-2082137	TS3006-9	R1.07	4 x 10	5.8		1.54	5	3.30	0	0.26	85	
1.2872	550-2082153	TS3006-11	R1.08	4 x 10	7.4		2.09	6	5.27	0	0.54	97	
1.2885	550-2082159	TS3006-11	R1.08	10	8.6		1.93	6	6.19	0	0.08	92	Broke 46.5
	C428/F417/ AA195												
1.2772	550-2082172	TS3006-1	R1.08	5.5	4.5		1.40	1	2.10	0	0.00	80	Broke 48, Arcing
1.2858	550-2082165	TS3006-1	R1.08	6.9	3.2		0.55	3	1.67	0	0.68	90	PH's, Lost DP
1.2778	550-2082059	TS3006-2	R1.08	10 + 4.1	29.3		9.50	0	16.44	0	1.26	95	Severe Corr. @ Chuck
1.2773	500-2082067	TS3006-3	R1.08	9.0	4.6		2.16	0	1.48	0	0.76	90	Broke 45.8 w/Corr.
1.2788	550-2082070	TS3006-3	R1.08	4 x 10	7.8		0.49	0	5.12	0	0.99	95	
1.2774	550-2082081	TS3006-4	R1.08	3 x 10 + 2.2 + 7.8	9.0		0.68	0	6.21	1	1.31	98	
1.2786	550-2082086	TS3006-4	R1.08	10 + 3.8	17.5		2.34	0	6.18	0	0.28	90	Surface Corr., Corr. Break 44
1.2775	550-2082089	TS3006-5	R1.08	10 + 3.3	27.0		8.37	0	12.99	0	0.14	92	Surface Corr., Corr. Break 49
1.2787	550-2082097	TS3006-5	R1.08	10 + 8.5	41.1		8.23	6	13.67	0	0.50	70	Surface Corr., Broke 11 and 44
1.2776	550-2082098	TS3006-6	R1.08	3 x 10 + 7.8	7.3		0.71	0	4.95	0	0.94	90	Seal Failed

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TABLE C-4 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2800	550-2082101	TS3006-6	R1.08	10 + 8.0	8.4		0.84	1	6.39	2	0.17	99	PH's, Lost DP
1.2780	550-2082110	TS3006-7	R1.07	4 x 10	9.1		0.97	0	4.97	0	0.86	95	
1.2802	550-2082115	TS3006-7	R1.08	5 x 10 + 1.0	26.0		2.14	33	12.79	20	9.07	94	Lost DP
1.2781	550-2082122	TS3006-8	R1.07	4 x 10	7.1		1.49	0	5.14	0	0.97	95	
1.2803	550-2082125	TS3006-8	R1.09	0	4.7		-	0	-	0	-	90	Broke 3, 46, Arcing
1.2782	550-2082135	TS3006-9	R1.07	4 x 10	7.0		1.87	0	4.93	2	0.90	100	
1.2804	550-2082139	TS3006-9	R1.09	4 x 10 + 3.2	15.8		2.92	5	11.31	6	0.87	80	PH's, Lost DP
1.2783	550-2082141	TS3006-10	R1.07	4 x 10	6.9		1.21	0	5.41	0	0.88	100	
1.2805	550-2082145	TS3006-10	R1.09	10 + 5.3	10.3		2.42	6	7.60	1	0.88	95	PH's, Broke 48.4
1.2784	550-2082155	TS3006-11	R1.07	4 x 10	7.0		2.17	0	3.83	3	1.80	100	
1.2799	550-2082157	TS3006-11	R1.08	10	6.3		1.37	0	3.86	0	0.07	95	Broke 49.5, Arcing
	C429/F418/ AA196												
1.2812	400-2082205	TS 3009	R1.09	7.2	2.5		0.49	0	0.41	1	0.50	95	Broke at 4.5
1.2813	341-1046502	M3	R1.09	3 x 10 + 7.2	13.9		0.84	1	6.74	3	1.62	80	Broke at 49, Arcing
1.2816	400-2082208	TS 3009	R1.09	10 + 3.5	4.7		0.56	0	2.52	3	1.12	85	Corr. Holes, Lost DP
1.2817	400-2082209	TS 3009	R1.09	4 x 10	11.2		0.89	1	5.87	8	1.04	80	
1.2821	400-2082210	TS 3009	R1.09	3 x 10 + 2.0	8.7		0.63	0	5.66	3	1.31	100	Corr. Holes, Lost DP
1.2824	256-1046555	M3	R1.09	4 x 10	11.0		1.41	0	6.34	11	1.95	100	
1.2828	400-2082211	TS 3009	R1.09	2 x 10	9.7		0.31	1	5.47	2	1.72	80	Broke at 41, Corr.
1.2831	400-2082213	TS 3009	R1.09	4 x 10	8.2		0.51	0	4.66	1	1.43	100	
1.2832	635-2082240	TS 3010	R1.09	4 x 10	13.5		2.00	0	7.19	0	1.11	90	
1.2833	635-2082230	TS 3010	R1.09	10	8.0		0.35	0	6.04	0	0.01	90	Broke 48, Corr., Arcing
1.2835	635-2082250	TS 3010	R1.08	10 + 6.8	7.0		0.76	0	2.35	2	0.00	90	Broke 47, Corr., Arcing

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TABLE C-4 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/Mo (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2857	635-2082234	TS 3010	R1.08	2 x 10 + 6.8	7.1		-	1	-	4	-	90	Corr. Hole, Lost DP
1.2860	400-2082214	TS 3009	R1.09	4 x 10	9.1		0.93	0	5.41	3	1.36	97	
1.2863	635-2082245	TS 3010	R1.08	3 x 10 + 9.8	11.5		2.59	1	8.08	4	0.53	92	Corr. Hole 51, Lost DP
1.2864	400-2082216	TS 3009	R1.09	10 + 2.5	3.8		0.59	0	2.18	2	0.57	98	Corr. Hole 49, Lost DP
1.2856	635-2082244	TS 3010	R1.08	4 x 10	9.3		0.71	1	5.70	1	1.89	99	
1.2865	400-2082218	TS 3009	R1.09	5 + 15 + 10 + 1.0	10.1		0.65	6	5.57	1	2.08	100	Lost DP
1.2763	C431/F417/ AA195 550-1046634	GLF	R1.07	8.5	8.3		1.02	0	7.28	0	0.00	94	Broke 48, Corr.
1.2826	C431/F419/ AA195 550-1046441	GLF	R1.09	4 x 10	33.9		8.19	230	12.27	50	0.84	97	
1.2840	C432/F419/ AA197 550-1046623	M3	R1.08	2 x 10 + 8.6	13.0		1.17	0	6.09	0	0.44	95	Broke at 45.8, Arcing
1.2839	C432/F420/ AA197 550-1046657	M3	R1.08	10 + 6.9	6.6		1.65	2	6.19	7	0.26	100	PH's, Lost DP
1.2851	550-1046643	M3	R1.08	2 x 10 + 0.8	7.5		0.40	58	7.40	0	0.20	100	Broke 49, Arcing
1.2845	C432/F421/ AA197 341-1046500	M3	R1.08	4 x 10	5.9		0.88	0	3.82	0	0.50	95	

TABLE C-5 (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2719	C412/F411/ F414 550-2081997	TS 3003	R1.07	9.0	5.4			0		5		100	Abort, PH's
1.2718 1.2721	C413/F410/ F414 550-1046158 550-1046176	TS 3005 TS 3005	R1.07 D1.01	4 x 10 6 x 10	10.4 6.0		2.69 1.88	2 1	5.20 1.28	0 0	2.31 2.84	85 95	Hot End Cracks Hot End Cracks
1.2746 1.2696	C422/C423/ F410 413-1046526 413-1046444	M3 GLF	R1.07 R1.07	3 x 10 + 2.5 10 + 5.0	4.3 9.3		0.21 -	0 0	2.13 -	0 9	- -	97 85	BAR Corr., Lost DP Broke 51, Corr.
1.2747 1.2697	C422/C423/ F411 630-1046701 550-1046434	M3 GLF	R1.07 R1.07	10 + 4.5 10 + 5.0	9.8 7.3			0 0		0 5		100 97	Broke 48, Corr. PH's & Cracks, Hot End
1.2695 1.2750	C422/C423/ F412 550-1046452 630-1046708	GLF M3	R1.07 R1.07	4 x 10 8.0	18.6 1.3		0.21	1 0	2.16	0 0	16.26	80 100	Hot End Cracks Hot End Crack
1.2761 1.2888	C422/C423/ F413 550-1046463 630-1046702	GLF M3	R1.07 R1.08	2 x 10 10 + 6.5	14.0 5.8			23 0		0 4		100 100	PH's, Lost DP PH's, Lost DP

TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2789	C429/F418	TS 3010	R1.08	2 x 10 + 0.4	8.4		0.49	0	2.78	0	0.43	98	Broke 49 w/Corr.
1.2790	635-2082236	TS 3010	R1.08	10 + 0.4	9.6		2.28	0	6.62	0	0.20	88	Broke 49 w/Corr.
1.2791	635-2082241	TS 3010	R1.08	10 + 0.5	5.2		1.21	0	4.17	4	0.42	95	PH's, Lost DP
1.2818	635-2082254	TS 3010	R1.08	10 + 0.5	5.2		1.21	0	4.17	4	0.42	95	PH's, Lost DP
1.2818	550-1046596	M3	R1.09	4 x 10	10.2		2.14	0	5.79	0	0.00	95	PH's, Lost DP
1.2838	310-1046568	M3	R1.08	4 x 10	6.2		1.37	0	3.94	0	0.89	100	PH's, Lost DP
1.2859	635-2082248	TS 3010	R1.08	8.5	7.2		-	0	-	3	-	90	Lost DP, Broke 47
1.2861	635-2082237	TS 3010	R1.08	3 x 10 + 3.5	8.7		2.44	0	3.98	2	3.08	98	PH's, Lost DP
1.2762	C431/F417	GLF	R1.07	10 + 2.6	7.7		1.29	1	3.93	0	0.28	100	Broke 45.8 w/Corr.
1.2810	C431/F419	GLF	R1.08	2 x 10	17.1		2.96	17	8.80	1	0.44	100	Broke 48 w/Corr.
1.2811	C431/F420	GLF	R1.08	7.5	5.9		0.16	30	4.85	4	0.09	100	PH's, Lost DP
1.2802	C431/F421	GLF	R1.09	10	5.2		-	0	-	0	-	100	Broke at 48 in Ramp
1.2841	C432/F419	M3	R1.08	2 x 10 + 0.3	11.1		0.93	3	10.00	4	0.17	100	Broke at 47.9, Corr.
1.2806	550-1046637	M3	R1.09	10 + 1.0	7.1		0.39	0	1.64	0	0.07	99	Broke 47.3, Arcing
1.2807	C432/F420	M3	R1.09	8.4	5.7		0.34	0	3.82	0	0.04	100	Broke 48.7, Arcing
1.2809	C432/F421	M3	R1.09	6.0	3.6		0.70	0	3.16	0	0.24	99	Broke 48.7 in Ramp
1.2844	375-1046515	M3	R1.08	10.0	2.9		0.63	1	0.78	0	0.09	100	Broke 39, Corr. Hole
	375-1046520	M3	R1.08	10.0	2.9		0.63	1	0.78	0	0.09	100	Broke 39, Corr. Hole

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TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2918	L328/M152 630-47143	SX5	R1.09	3.8 + 3.2	15.5	0	0.16	1	15.41	2	0.00		Shutdown 3.8 Lost Seal and 3.2 Lost DP
1.2919	243-47475	AXM	R1.09	1.7	3.2	0		0		0			Broke 5-7/8 Arcing, 8-3/8, 45 Mech.
1.2957	243-47476	AXM	R1.09	0	2.9	0		0		0			Broke 5-7/8 Arcing
1.2958	630-47154	SX5	R1.09	6.2	2.5	0		0		0			Broke at 2-1/2, 14-1/2, 26, 29-1/4, and 49
1.3015	243-47477	AXM	R1.09	2.9	5.1	0		0		0			Broke 7" Corr. w/Arc
1.3016	630-47171	SX5	R1.09	4.1	1.1	0		0		0			4-1/2, 47-3/4 Mech. Broke 15-1/4, 49 Mech.
1.2945	C442/C444/ M153 630-47150	SX5	R1.09	10 + 10	17.8	0	0.23	1	16.38	0	0.00		Broke at 45-1/4" Corrosion Pocket
1.2952	630-47155	SX5	R1.09	10 + 3.5	16.8	0	0.42	6	14.99	2	0.00		Seal Mark at 51-3/4
1.2965	630-47188	SX5	R1.09	10 + 4.5	9.8	0	0.31	3	9.65	0	0.08		Broke 46-1/4 Corr. Pocket and Arcing
1.2970	550-46622	M3	R1.09	10 + 5.0	7.9	0	0.47	3	5.41	0	0.18		Shutdown 5.0 Cycle 2, Lost DP
1.2979	630-47189	SX5	R1.09	10 + 1.7	15.2	0	0.42	14	13.92	0	0.00		Broke 47-3/4, Lo Corr. Pocket 47-49
1.2984	550-46625	M3	R1.09	3 x 10 + 3.0 + 5.0 + 22	13.8	0	1.11	0	9.95	0	0.92		

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TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2935	L329/M154 630-47197	AXM	R1.09	2 x 10 + 3.5	9.6	0	1.12	1	8.24	0	0.27		Replaced Chuck After 2 x 20, Broke at 46 Broke at 31" Corrosion Shutdown 4.2, Lost Seal & 50 Lost DP Shutdown 8.8 Cycle 1, Lost DP Shutdown, Lost DP, Broke 48-1/2 Unloading
1.2936	243-47468	AXM	R1.09	5.2	6.4	0	1.69	0	0.89	0	0.06		
1.2950	243-47482	AXM	R1.09	3 x 10 + 4.2 + 5.8 + 10	12.5	0	0.73	0	6.85	0	1.18		
1.2968	630-46941	GLF	R1.09	8.8	10.5	0	0.10	1	9.57	0	0.03		
1.2980	630-46945	GLF	R1.09	10	9.7	0	0.09	0	8.80	5	0.43		
1.2987	243-47488	AXM	R1.09	2 x 10 + 5.2 + 14.8 + 2 x 10	12.4	0	0.08	2	9.23	0	0.97		
1.3017	630-47446	AXM	R1.09	0	3.1	0		0		0			
1.2937	L330/M155 630-47203	SX5	R1.09	10 + 1.0	12.6	0	0.41	17	11.69	7	0.12		Broke 48-1/4 Corr, Surface Corr. 45.50
1.2939	243-47471	AXM	R1.09	4 x 10 + 4.2 + 13	15.4	0	2.32	60	9.39	0	1.62		Broke at 45-1/4 Corr. Pocket Lost DP 8.0, Surface Corr. 35 - 49
1.2946	630-46932	GLF	R1.09	10 + 1.0	9.4	0	0.75	2	6.37	3	1.74		
1.2954	243-47484	AXM	R1.09	3 x 10 + 3.5 + 16.5 + 8.0	12.4	0	1.82	1	7.48	2	1.25		

TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2955	630-46933	GLF	R1.09	3 x 10 + 1.7	10.1	0	2.73	0	6.59	0	0.33		Broke 48-5/8 Unloading, Corr. Pocket at Break Broke 3 & 22 Arc, 5, 43, and 48 Mech.
1.3018	630-47452	AXM	R1.09	1.4	5.8	0		0		0			
1.2975	C432/M157 550-46641	M3	R1.09	4 x 10 + 2.7 + 17.3	18.5	0	1.05	2	14.67	0	0.95		Shutdown 2.7, Lost Seal Broke 47-1/4 Unloading, Lg. Corr. Pocket
1.2983	550-46642	M3	R1.09	4 x 10 + 4.0 + 16.0	15.8	0	1.39	6	12.12	0	0.87		
1.2990	550-46649	M3	R1.09	3 x 10	8.4	0	1.09	0	5.33	0	0.18		
1.2995	C432/M158 550-46674	M3	R1.09	8.1	5.6	0	0.68	0	0.76	0	0.00		Broke 46-1/4 Corr. Bores Enlg. Toward Hot End Broke 47-1/2 Lg. Corr. Pocket and Arcing Broke 47-3/8, Corr. w/Arcing
1.3000	550-46648	M3	R1.09	10 + 0.2	16.7	0	0.18	3	15.15	0	0.00		
1.3007	550-46668	M3	R1.09	10 + 3.0 + 17.0 + 7.3	11.7	0	0.70	0	7.02	0	0.35		
1.3061	C432/M160 550-46653	M3	R1.09	10 + 1.5	5.6	0	0.45	3	4.29	0	0.40		Shutdown, Lost DP Broke at 45-1/2 Corr. Shutdown, Lost DP, Large, Corr. Holes Shutdown, Lost DP, Broke Unloading
1.3070	550-46652	M3	R1.09	10	5.4	0	0.34	0	4.85	0	0.11		
1.3078	256-46554	M3	R1.09	10 + 6.5	9.5	0	0.61	3	7.48	0	2.35		
1.3094	310-46570	M3	R1.09	4 x 10 + 1.0	15.4	0	1.29	0	13.15	0	0.41		

TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3049 1.3057 1.3034	L334/M160 630-47664 630-47665 630-47666	SX5 SX5 SX5	R1.09 R1.09 R1.09	2.6 3.5 3.6	1.1 2.0 1.2	0 0 0	- - -	0 0 0	- - -	0 0 0	- - -		Broke at 4-1/4" Mech. Broke at 4-3/4" Arc & 48-1/8 Mech. Broke at 2-3/4, 21-7/8 Mech.
1.3053 1.3062 1.3072	C427/M161 341-46503 375-46516 375-46514	M3 M3 M3	R1.09 R1.09 R1.09	3 x 10 + 2 x 10 + 5.5 3 x 10 + 3.0 2 x 10 + 7.7 + 12.3 + 2 x 10	12.0 6.6 24.0	0 0 0	1.46 0.55 1.24	0 2 63	10.05 5.09 18.17	0 0 5	0.38 0.24 2.26		Lost Seal at 3 x 10, Lost DP at 5.5 Shutdown, Lost DP
1.3067 1.3068 1.3076 1.3081 1.3090 1.3115	L330/M156/ M162 550-47229 630-47204 550-47232 630-46938 243-47485 L335/M163 630-46871	AXM SX5 AXM GLF AXM GLF	R1.09 R1.09 R1.09 R1.09 R1.09 R1.09	3 x 10 + 4 + 16 + 10 2 x 10 7.6 4 x 10 + 5 + 15 4 x 10 + 3.0 + 17 8.9	12.6 5.7 1.6 13.1 9.3 15.5	0 0 0 0 0 0	0.96 0.37 0.40 0.96 0.49 0.20	0 7 0 0 1 9	10.12 5.27 0.79 10.39 5.66 14.58	0 0 0 0 0 0	0.60 0.06 0.03 0.55 0.61 0		Lost DP, Seal Mark 51-7/8 Broke at 5-1/2, Mech. w/Arc Lost Seal 5' Cycle 5 Lost Seal 3' Cycle 5 Broke at 47-3/4 Corr. Pocket

TABLE C-5 (CONT.) (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3116	L336/M163 630-47677	SX5	R1.09	8.5	6.1	0	0.12	0	5.90	0	0		Broke 48-3/4 Corr. Pocket
1.3208	L348/M168 200-1047891	AXM	R1.09	4 x 10	7.3	0	0.61	0	5.26	4	0.52		Shutdown, Lost DP
1.3209	630-1047623	SX5	R1.09	3 x 10 x 5.0	7.2	0	0.30	0	5.92	9	0.48		Shutdown, Lost DP
1.3210	400-1048085	AXF	R1.09	4.9	4.6	0	-	0	-	0	-		Broke at 4-1/2 Mech.
1.3213	391-1047973	AXM	R1.09	3 x 10 + 1 + 15 + 5	7.2	0	1.04	0	5.81	0	0.87		Rechucked 1" Cycle 4, Stop Badly Corr.
1.3214	630-1047610	SX5	R1.09	6 x 10	10.1	1	1.66	0	8.06	0	0.97		
1.3215	630-1047611	SX5	A6.06	6 x 10	4.2	0	1.68	0	3.50	4	0.77		
1.3216	630-1047612	SX5	D1.01	5 x 10 + 1.0	7.4	0	0.87	0	6.30	3	0.81		Shutdown, Lost DP
1.3217	630-1047954	AXM	R1.09	4 x 10 + 1 + 19	7.1	0	0.94	0	5.68	0	0.50		Rechucked at 1" Cycle 5
1.3219	400-1048041	AXF	R1.09	4.2	3.5	0	-	0	-	0	-		Broke at 2-3/4 Mech. w/Arcing
1.3220	630-1047507	AXM	R1.09	10 + 7 + 13 + 11 + 10	8.5	0	0.86	0	6.93	0	0.71		Rechucked at 7" Seal 90% Corr.
1.3224	630-1048046	AXF	R1.09	4 x 10 + 2 + 18	7.8	0	1.46	0	4.82	0	1.49		Rechucked at 2 Cycle 5
1.3239	391-1047974	AXM	A6.06	6 x 10	3.0	0	0.35	0	2.79	0	0.18		
1.3240	630-1047956	AXM	A6.06	6 x 10	3.9	0	0.71	0	2.72	0	0.32		
1.3241	630-1047512	AXM	A6.06	6 x 10	3.2	0	0.52	0	2.38	0	0.35		
1.3256	630-1047512	AXM	A6.06	5 x 10 + 1	6.6	0	1.00	0	7.86	0	0.73		Lost DP, Stop Corroded
1.3271	400-1048042	AXF	A6.07	2 x 10 + 6 + 14 + 2 x 10	12.3	0	0.99	0	9.65	1	0.82		Rechucked 6' Cycle 8
1.3272	400-1048086	AXF	A6.07	2 x 10 + 0.2	12.4	0	0.61	1	11.73	0	0.06		Broke at 45-1/4 Corr. Poc.

TABLE C-6 (CRD)
COATING DEVELOPMENT EVALUATION
GEM NbC/GEM ZrC/HED H.T. (CRD) *

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.2997	C442/C444/ M152/M159 630-47199	GLF	R1.09	10 + 8.0	4.8	0	0.23	3	4.24	0	0.14		Shutdown 8.0, Lost DP
1.2996 1.3012	L329/M154/ M159 630-46948 243-47489	GLF AXM	R1.09 R1.09	10 + 3.2 6 x 10	4.8 35.4	0 0	0.12 0.12	2 95	2.48 27.29	0 19	0.27 1.66		Shutdown 3.2, Lost DP Surface Corr. 40-49, Flaking on BAR

* Element heat treated at HED coating temperatures.

TABLE C-7 (CRD)
COATING DEVELOPMENT EVALUATION
NbC GEM/ZrC GEM/ZrC HED (CRD)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3139	L335/M163/ M165 630-46868	GLF	R1.09	2 x 10 + 1.0	7.4	0	0.86	0	4.31	0	2.01		Broke at 47, Corr. Pocket w/Arcing Lost Seal 4' Cycle 4
1.3142	630-46869	GLF	R1.09	3 x 10 + 4 + 16 + 10	15.5	0	0.21	0	12.13	0	12.87		
1.3144	L336/M163/ M165 630-47674	SX5	R1.09	5 x 10	8.9	0	0.59	2	7.39	0	0.36		Lost DP, Blistering 48- 49

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TABLE C-8 (CRD)
COATING DEVELOPMENT EVALUATION
GEM ZrC (U)

C/Test No.	S/N	Matrix	Test	Time	Total Wt. Loss	PH	0-25 ΔW	PH	25-50 ΔW	PH	50-52 ΔW	BAR	Comments
1.3050	M161 630-47685	SX5	R1.09	2 x 10	8.5	0	0.18	1	6.92	0	0.10		Broke 42-1/2, Large Corr. Pocket
1.3055	630-47690	SX5	R1.09	4 x 10	25.3	0	0.70	20	21.05	0	0.68		Broke at 38-3/4, Pocket Corr. w/Arcing
1.3063	630-47806	AXM	R1.09	0	1.6	0	-	0	-	0	-		Broke at 49-1/8 Arcing
1.3071	630-47804	AXM	R1.09	2 x 10 + 5.0	8.9	0	0.38	5	7.29	0	1.14		Shutdown, Lost DP