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December 1, 1969

Westinghouse Astronuclear Laboratory

**PEWEE-2 HIGH EXPANSION MATRIX
DEVELOPMENT PROGRAM (U)**

WFED-TS-3016 - FINAL REPORT

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PEWEE-2 HIGH EXPANSION MATRIX DEVELOPMENT PROGRAM (U)

WFED-TS-3016 - FINAL REPORT

SPECIAL REVIEW FINAL DETERMINATION	Reviewers	Class.	Date
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ABSTRACT (U)

(U)

This report covers the developmental work done by WNCO to produce and characterize a high expansion matrix for use in the Pewee 2 reactor. Information is included on both fabrication and matrix performance. It was found that basic NERVA fabrication technology could be applied directly to the fabrication of high expansion element with only minor difficulties. However, the major problem with the high expansion element is thermal stress. Irrespective of this problem, the AXM based fuel element developed in this study is sufficiently good to be used in Pewee 2.

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1.0 INTRODUCTION (U)

1.1 PURPOSE AND OBJECTIVES (U)

(U) The purpose of this program was to develop and characterize a high expansion matrix for use in the Pewee 2 reactor. Two (2) primary objectives were set. The first was to provide a high coefficient of thermal expansion (HCTE) element which demonstrated a potential for use in the R-1 reactor. The second was to determine the thermal stress resistance of HCTE fuel elements. Secondary objectives were to provide HCTE elements for other programs such as coating development and to generate data on the properties of high expansion matrices.

1.2 BACKGROUND (U)

(CRD) The NRX-A6 vintage fuel element matrix had a longitudinal thermal expansion of about 3.5 to $4.0 \times 10^{-6}/^{\circ}\text{C}$. The NbC coating on this element had an expansion of about $7.2 \times 10^{-6}/^{\circ}\text{C}$. This mismatch has long plagued the fuel development engineers because it causes several problems. If the coating is applied so that it is very adherent to the matrix, large tensile stresses are induced in the coating on cooling down from deposition and operating temperature. This tends to crack the coating and the matrix. If the coating is applied so that it is loosely bound to the matrix, it still cracks due to tensile stresses on cooldown from deposition temperature. However, although these coating cracks close when the element is heated to or above coating temperature, there are regions at the cold end of the element that do not get to deposition temperature during core operation. The matrix under these open cracks is then exposed directly to hot hydrogen causing gross "midband" corrosion.

(CRD) Several solutions to these problems have been made. One solution was to deposit the coating at a lower temperature (GEM or Gas End Methane process) and thereby minimize the stress by lowering the temperature differential on cooldown.

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(CRD) This worked to some extent for one cycle. However, the coating deposited by this technique was extremely adherent and when the element was heated to operating temperature, the coating annealed and acted as if it had been deposited at the higher temperature. On cool-down, new, larger cracks in both the coating and matrix were formed. In addition, the matrix cracks often split and exposed fuel beads rendering them susceptible to hydrolysis.

(CRD) Another solution that was used in the A6 reactor was to deposit molybdenum in the exposed cracks at very low temperatures (less than 300°C). The theory behind this solution was that a flash coating of the metal would be deposited in the cracks and, on heating when the cracks close, this metal would be "extruded" into the shape of the crack and seal it completely. This also worked well for one cycle, as the performance of the A6 shows. However, molybdenum is a poison and it tended to reduce the reactivity of the fuel. Also, some of the molybdenum tended to be non-adherent and caused air impedance changes during tests.

(CRD) Some other exotic attempts to solve the mismatch problem have also been tried. One method used the principle of a completely non-adherent tube of niobium metal inserted into the element bore as a protective liner. This method proved impractical.

(CRD) For the purposes of the A6 type reactor, molybdenum overcoating or GEM coating may have been sufficient because it was designed for only one cycle to full power (although GEM coating has been tied to bead hydrolysis and pinholing). However, future missions for the NERVA engines demand multiple cycling capability and for this use the mismatch problem must either be solved or minimized.

(CRD) The most obvious solution to the mismatch problem is to eliminate it. This was recognized early in the program. It was deemed impossible to significantly lower the CTE of NbC, so it seemed practical to raise the CTE of the matrix. This could and had been done.

(U) The original attempt at making a HCTE matrix was unsuccessful. A special air blown petroleum coke (Robinson) was used by LASL in fabricating HCTE fuel elements. These could not be corrosion tested because they tended to disintegrate. The problem

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- (U) was immediately recognized as being thermal stress oriented. However, at this time the problem was deemed insolvable because the channel locations could not be improved and the graphite could not be made stronger. Therefore, the effort was shelved.
- (U) The idea was resurrected by WANL during the A6 development program. Again, Robinson coke was chosen as the basic flour. These elements, having somewhat improved properties, could be tested and did slightly out perform the basic A6, low expansion matrix. However, since A6 was only to run one cycle, the risk due to thermal stress was felt to be greater than the modest benefit gained from high expansion in low cycle number cores.
- (U) After A6 and its outstanding success, attention was redirected toward an element with cyclic capability. It became apparent that the A6 fuel element would not readily meet this requirement. Consequently, the use of high expansion matrices was investigated further, this time with a new material, POCO Graphite, Inc. grade AXZ. WANL fabricated several of these elements under Test Specification 3001 (IIGa) specifically to meet the demands of the GEM coat and cyclic capability. These elements gave sufficiently promising results to warrant serious evaluation as a core candidate.
- (U) The decision to make Pewee 2 a high expansion core was made on the success of the 3001 type elements. Three (3) major steps had to be taken. The first was to generate sufficient matrix property and characterization data on the element so that theoretical assessments of its capability could be made. The second was to determine if the HCTE element could stand the thermal stress environment of Pewee 2 and, eventually, R-1. The third was to determine if routine production techniques could be applied to this material or if major vendor modifications had to be made to fabricate fuel elements from it.
- (U) This program was written to verify that these steps could be taken.

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2.0 EXPERIMENTAL APPROACH (U)

(U) The approach was to evaluate the effect of CTE on corrosion performance and choose the most attractive element. To do this, it was decided that three (3) types should be evaluated for use in making a HCTE core. POCO grade AXM was chosen over AXZ (the 3001 material) because it appeared to have some more favorable properties, i.e., a higher CTE and higher bulk density. Speer grade SX-5 was chosen for the second candidate because previous experience indicated it would have an intermediate CTE. Gilsonite coke was chosen as the third candidate. These three (3) flours were to be fabricated into elements and the flour which gave the best element was to be used in Pewee 2. WNCO was given the sole responsibility for the evaluation of SX-5. Y-12 was given sole responsibility for Gilsonite. Both facilities were to evaluate AXM.

(U) Y-12 purchased the bulk POCO AXM pucks and ground them into flour. WNCO bought SX-5 flour directly from Speer. At the beginning of the work approximately 6000 pounds of SX-5 and 3000 pounds of AXM were available for both evaluation and core production.

(U) The WNCO evaluation plan involved two complete iterations of matrix fabrication data prior to the initiation of the actual Pewee 2 core extrusion. The first iteration (Phase I) was to yield such data as binder levels, preliminary tooling set ups, inherent matrix fabrication problems, and preliminary property data. The second iteration (Phase II) would yield actual core use die setups, more extensive matrix properties, matrix characteristics, elements to act as quality control standards, coating development elements, and elements for corrosion testing. A combination of the data from both iterations was to be used in producing and characterizing the Pewee 2 type HCTE element.

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3.0 PROCESSING (U)

3.1 PHASE I - SCOPING STUDY (U)

3.1.1 Flour Procurement and Flour Details (U)

(CRD)

The two flours (AXM and SX-5) were purchased independently by the two manufacturers, Y-12 and WNCO. Y-12 purchased AXM billets from POCO Graphite, Inc. These billets were subsequently ground by Y-12 and the flour was fired at 2500°C.

WNCO purchased the SX-5 as final flour from Speer Graphite, Inc. The flour was ground by Speer to the standard NERVA flour size specification. No further heat treatment was done on the SX-5 material. A listing of several properties of the flours used on TS-3016 is presented in Table 3.1.

3.1.2 Extrusion (U)

(U)

Extrusion of the Phase I fuel elements was accomplished by WNCO in November and December of 1968. Both fueled runs were preceded by non-fueled extrusions to establish binder levels. The quantities and types of elements extruded are detailed in Table 3.2. Previous WNCO experience with SX-5 indicated that elements made with this flour would have high leak rates, so the scoping study on the SX-5 elements was designed to yield baseline elements as well as some experimental elements designed to have low leak rates. WNCO experience on POCO flours, however, indicated the opposite to be true, so the scoping study on POCO was designed to study loading effects. Both baseline types were made with two (2) binder levels. The extrusion details of the Phase I extrusions are also detailed in Table 3.2.

3.1.3 Thermal Processing (U)

(CRD)

Curing, baking, and graphitizing were all accomplished by the normal WNCO thermal cycles. One difficulty was noted during heat treating which was to plague the work. These elements shrank significantly less than normal during heat treatment. This caused great difficulty in loading the fixtures, especially at the higher loadings.

TABLE 3-1
(U) FLOUR PROPERTIES (U)
TS-3016

Flour Type	Particle Size Distribution		Interlayer Spacing	Percent Graphitization	Surface Area	Chemical Analysis
	Tyler Mesh	% By Weight				
SX-5	+ 60	0.2	3.3695 Å	65.15	5.09 m ² /gm	Ash 0.06%
	+ 65	0.4				Iron 47 ppm
	+ 100	3.2				Silicon 76 ppm
	+ 150	18.2				Boron 2.9 ppm
	+ 200	22.4				Moisture 0.01%
	+ 270	14.2				
	+ 325	8.4				
	- 325	32.8				
AXM-5Q Shipment #1 from Y-12 500 lbs.	+ 60	0.2	3.3791 Å	52.01	4.42 m ² /gm (Krypton 85 technique) 5.42 m ² /gm (Y-12 Bet. Value)	Ash 0.09%
	+ 100	25.7				Iron 48 ppm
	+ 160	15.4				Silicon 9 ppm
	+ 200	10.9				Boron 1.0 ppm
	+ 240	4.5				Moisture 0.01%
	+ 325	6.0				
	- 325	37.3				
AXM-5Q Shipment #2 from Y-12 1500 lbs. Core Cand.	+ 60	0.2	3.3776 Å	54.40	2.50 m ² /gm	Ash 0.04%
	+ 100	22.3				Iron 6.2 ppm
	+ 150	15.5				Silicon 4.5 ppm
	+ 200	10.0				Boron 1.0 ppm
	+ 270	6.7				Moisture 0.00%
	+ 325	4.7				
	- 325	40.6				
GLF (standard)	+ 60	1.2	3.3613 Å	79.3	3.53	Ash 22.0 ppm
	+ 100	12.9				Iron 3.5 ppm
	+ 140	18.7				Silicon 26.0 ppm
	+ 200	13.2				Boron 3.0 ppm
	+ 270	10.9				Moisture 74 ppm
	+ 325	6.7				
	- 325	35.9				

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TABLE 3-2

(CRD) EXTRUSION DETAILS - Phase I: TS-3016 (U)

Flour Type	Loading mg ^U /cc	DCI Ratio	Binder Level	Press Force (tons)	Ext. Rate (in/min)	Qty.	Remarks
SX-5	0	85/15	31	---	---	---	Too wet to form
SX-5	0	85/15	29	45	240	9	
SX-5	0	85/15	28	65	240	3	
SX-5	0	85/15	27	63	240	5	
SX-5	0	85/15	26	73	240	4	
SX-5	0	85/15	24	107	240	3	
SX-5	0	85/15	23	135	240	3	
SX-5	0	82/18	27	55	240	4	
SX-5	0	82/18	26	72	240	4	
SX-5	0	82/18	25	80	240	5	
SX-5	0	82/18	24	102	260	4	
SX-5	0	82/18	23	115	230	3	Cracking on final extrusion
SX-5	0	77/23	26	57	230	3	
SX-5	0	77/23	25	69	240	4	
SX-5	0	77/23	22	120	230	3	Cracking on final extrusion
SX-5	0	77/23	21	175	240	2	Cracking on final extrusion
AXM	0	85/15	30	110	250	4	
AXM	0	85/15	32	85	230	3	
AXM	0	85/15	33	75	230	2	
AXM	0	85/15	34	55	230	4	Extrusion cracks
AXM	0	85/15	35	---	---	---	Too wet to form
SX-5	630	85/15	24	125	250	8	Cracking on final pass
SX-5	630	85/15	25	102	230	12	Cracking on final pass
SX-5	630	82/18	24	104	244	12	
SX-5	630	77/23	23.5	120	240	12	
SX-5 (sized)	630	85/15	24	130	240	11	
GLF-89772 #2	630	85/15	27.5	90	240	13	
AXM	630	85/15	30	104	244	12	
AXM	630	85/15	31	88	244	12	
AXM	243	85/15	30	108	250	12	
AXM	243	85/15	31	88	250	12	

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(CRD) The elements were approximately five (5) to ten (10) mils larger across flats than previous as-graphed elements. To alleviate the fixture loading problem, a new extrusion die was purchased with smaller than normal as-extruded across flats dimensions (0.800 inch as opposed to the normal 0.813 inch). Subsequent extrusions have shown this to be an adequate solution with no detrimental effects on element properties. To solve the immediate problem of loading the fixtures, a tool was constructed to skim the corners of the elements so that the hex could fit in the circular graph log holes. This worked adequately also.

3.1.4 Tipping (CRD)

(CRD) Tipping was accomplished by the Pewee 1 brazing process without incident.

3.1.5 Machining (U)

(CRD) The previously mentioned oversize problem led to some difficulty in machining. Apparently, any element that enters the WNCO standard diamond mill set-up with across flats dimensions greater than about 0.790 inch will be machined with slightly feathered corners. This roughness is noticeable and borders on element rejection by the inspectors. For purposes of this experiment, the feather was considered insignificant. Further work illustrated that this could be solved by variation in mill feed rate. However, the new die mentioned in 3.1.3 was, subsequently, shown to alleviate this problem.

3.1.6 Leaching (U)

(CRD) Leaching was accomplished by the recommended Pewee 2, 2100°C leaching process. No unusual weight losses were noted.

3.1.7 Coating and Corrosion Testing (U)

(CRD) The TS-3016 elements were transferred to TS-3012 or TS-3017 for coating and corrosion testing and a discussion of these processes is beyond the scope of this report. However, most elements received an NbC GEM base coat and a ZrC HED overcoat and were tested under R1.09 or A6.06 conditions for multiple ten (10) minute cycles. A listing of the parameters for these two (2) tests is given in Table 3.3.

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TABLE 3-3

(CRD) TS-3016, PHASES I AND II, NOMINAL CORROSION TEST CONDITIONS (U)

1. Test Designation	R1.09	A6.06	A6.07
2. Surface Temperature at Control Station 49.6"	4980 + 100°R - 150	4800°R (Nominal)	4800°R (Nominal)
3. Test Duration	N x 10 min.	N x 10 min.	N x 10 min.
4. Power	950 ± 10 KW	880 ± 10 KW	880 ± 10 KW
5. Hydrogen Flow	600 ± 10 SCFM	600 ± 10 SCFM	600 ± 10 SCFM
6. Bore Overpressure at 20"	30 psi	30 ± 5 psi	30 ± 5 psi
7. Bore Exit Pressure	435 psig	435 psig	435 psig
8. Hot End Chuck	6 Finger	As per daily test priority	As per daily test priority
9. Power Ramp Duration	3 Minutes	1 Minute	3 Minutes

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3.1.8 Thermal Stress Testing (U)

- (U) The elements used for thermal stress analysis and their respective coating runs are listed in Table 3.4. Three 14-inch sections were cut from each element. The sections were shipped to LASL, N-7, for the standard, unshielded, thermal stress test.

3.2 PHASE II - PREPRODUCTION (U)

3.2.1 Background (U)

- (U) A delay was experienced in the delivery of the AXM which was expected to cause a delay of the core production, should AXM be chosen as the core flour. It was decided to minimize this delay by extruding elements for part of the Phase II program based only on extrusion knowledge gained in Phase I, rather than to wait for a full data package on the Phase I elements, as originally planned. Therefore, approximately one week after finishing the Phase I AXM extrusions, the Phase II extrusion was begun. Table 3.5 lists the planned yield of the Phase II extrusions and the uses of these elements.
- (CRD) After the extrusion of the stress and coating development elements, it was discovered that standard formulations of 85% AXM flour, 15% thermax, and 30% varcum would be very leaky at high loadings. This effected a change in the formulation to a lower binder level, 28 pph, and consequently higher extrusion pressures. The Quality Control standard elements were extruded by this technique.
- (CRD) The SX-5 Phase I elements were extruded in time to have sufficient data to pick a reliable process. Standard formulations were, as expected, highly permeable. Therefore, the most attractive formulation, i.e., 82/18 SX-5 to thermax ratio with 24% binder, was chosen for both the SX-5 support element extrusions and the SX-5 Quality Control standard extrusions.
- (U) Later data on the new process chosen for the AXM Quality Control standard extrusion also showed that elements made by the new process would be leaky. Some experimental batches were then extruded to try to solve this problem.

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(CRD) TS-3016 THERMAL STRESS TEST ELEMENTS AND THEIR RESPECTIVE COATING RUN (U)

<u>Serial Number</u>	<u>Flour</u>	<u>DCI</u>	<u>Binder Level</u>	<u>Coating Run</u>
630-1047141	SX-5	85/15	24	C442
630-1047151	SX-5	85/15	25	C442
630-1047163	SX-5	82/18	24	C442
630-1047175	SX-5	77/23	23.5	C442
630-1047185	SX-5 (siz.)	85/15	24	C442
630-1047194	GLF	85/15	27.5	C442
630-1047142	SX-5	85/15	24	C442/ C444
630-1047152	SX-5	85/15	25	C442/ C444
630-1047164	SX-5	82/18	24	C442/ C444
630-1047176	SX-5	77/23	23.5	C442/ C444
630-1047186	SX-5 (siz.)	85/15	24	C442/ C444
630-1047195	GLF	85/15	27.5	C442/ C444
630-1047140	SX-5	85/15	24	C441/ M150

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(CRD) TS-3016 THERMAL STRESS TEST ELEMENTS AND THEIR RESPECTIVE COATING RUN (U)

<u>Serial Number</u>	<u>Flour</u>	<u>DCI</u>	<u>Binder Level</u>	<u>Coating Run</u>
243-1047479	AXM	85/15	31	L328
243-1047481	AXM	85/15	31	L328
243-1047467	AXM	85/15	30	L328
243-1047469	AXM	85/15	30	L328
630-1047443	AXM	85/15	30	L328
630-1047445	AXM	85/15	30	L328
630-1047455	AXM	85/15	31	L328
630-1047457	AXM	85/15	31	L328

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3.2.2 Extrusion (U)

(CRD) Extrusion of the Phase II fuel elements was accomplished by WNCO in January and February of 1969. Standard die setups were used in all extrusions except the 573 and 630 loaded SX-5 standards. An attempt to cure the oversize problem mentioned in Paragraph 3.1.3 was made by using the 0.800 across flats die plenum. This was a new die part and some severe cracking was noted on extrusion with it. Some extrusions were made to wear in the part and later SX-5 elements were successfully extruded using it, producing the desired result. SX-5, at 24% binder, is prone to extrusion cracking and some difficulty was encountered in fabricating the elements even with the standard die setup. The SX-5 elements were extruded at a rate of 240 in/min, while the AXM elements were extruded at either 60 or 100 in/min. All other fabrication and mixing procedures were standard WNCO.

3.2.3 Thermal Processing (U)

(CRD) Curing, baking, and graphitizing were accomplished by normal WNCO procedures. The only problem encountered was that of the oversized across flats dimensions. This was solved by the pre-broaching technique described in 3.1.3.

3.2.4 Tipping (CRD)

(CRD) Tipping was accomplished by the standard WNCO molybdenum braze procedure. Fifteen (15) of the SX-5, 630 loaded fuel elements were tipped with extruded 50 v/o NbC - 50 v/o POCO AXZ graphite flour tips extruded by WNCO. These elements are still under evaluation, but the data so far gathered will be presented in the discussion section of this report.

3.2.5 Machining (U)

(CRD) Reaming was accomplished at WNCO with no incident. Milling was complicated by oversize elements. The AXM high loadings were the most difficult to mill. This apparently was caused by the change in binder level from 30 to 28 pph. Feathering on AB, CD, and EF corners was noted. This was minimized by slowing the mill feed drastically and by undersize extrusion as mentioned before.

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TABLE 3-5

(CRD) PLANNED EXTRUSIONS: PHASE II, TS-3016 (U)

<u>Flour Type</u>	<u>Loading (mg U/cc)</u>	<u>Batch Quantity</u>	<u>Use</u>
SX-5	630	10	Coating Development
SX-5	630	5	Hydrolysis Studies
SX-5	630	1	Stress Analysis
SX-5	521	1	Stress Analysis
SX-5	Variable	16	Quality Control Standards
-----	-----	-----	-----
AXM	630	10	Coating Development
AXM	630	5	Hydrolysis Studies
AXM	630	1	Stress Analysis
AXM	521	1	Stress Analysis
AXM	Variable	16	Quality Control Standards

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3.2.6 Leaching (U)

(CRD) Leaching was accomplished in the now standard WNCO 2100°C - 3 hour cycle.
The runs were made without incident.

3.2.7 Coating and Corrosion Testing (U)

(U) The Phase II elements were transferred to other specifications and programs after leach inspection. The data gained in coating and testing of these elements will be reported in either TS-3012 or TS-3017.

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4.0 DATA AND RESULTS (U)

4.1 EXTRUSION (U)

(CRD) Non-fueled elements of several binder level and thermax combinations were made with both SX-5 and AXM to determine working formulations that would yield low leak rates and normal extrusion parameters. Figure 4-1 illustrates how changes in binder levels change the extrusion force for SX-5 and AXM. Both sets of non-fueled extrusions were made at a rate of 240 in/min. The data presented is on the third extrusion pass only.

(CRD) Figure 4-2 shows how the extrusion force varied with loading on both the AXM and SX-5 Phase II elements. The WNCO batch formulation equation is designed to compensate for changes in loading so that any normal loadings can be made at constant forming pressure. The figure illustrates that the WNCO equation works well with SX-5, but some apparent systematic variation can be seen with AXM. The variation in the AXM may stem from one of two causes. The first explanation may be that the lack of experience with the flour could have led to the development of an incorrect determination of the empirical factor used in the formulation equation to account for the bead binder demand. This is unlikely, however, because similar lots of beads were used for both extrusions. The second cause may be related to the high extrusion forces used. The desired tonnages were relatively high. It was found that a binder level of 27% on AXM gave extrusion forces of 170 tons and a level of 26% could not be extruded. Slight weighing errors, therefore, would yield major changes in extrusion force. Since only one or two batches were made at each loading, the apparent difference may have been random and would disappear with more extrusion. The actual Pewee 2 extrusions did not show this apparent systematic variation.

4.2 LOADING (U)

(U) Some problem was noted in meeting the loading requirements on these elements. There were two different problem areas. The first was related to the decreased shrinkage on both types of elements which led to low actual loadings at high aim loadings. The second problem was a distinct taper in the loading of some of the elements.

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Figure 4-1. (CRD) Extrusion pressure as a function of binder level at a constant rate of 240 in/min on SX5 and AXM non-fuel elements. (U)

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Figure 4-2. (CRD) Effect of loading on extrusion force. (U)

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Figure 4-3. (CRD) Aim, as-graphitized versus final loadings for the Phase II, TS-3016 and Pewee 2 fuel elements. (U)

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(CRD) It has been previously mentioned that the high loaded AXM and SX-5 elements did not shrink normally. This lack of shrinkage resulted in a low loading due to a failure of the elements to densify sufficiently. This effect was not noted below about 450 mg U/cc where a plot of aim vs. final loading was linear. Marked deviation was noted above this loading, however, and to load the elements at 630 mg U/cc an as-graphitized loading of 710 mg U/cc was required. This is about 25 mg U/cc greater than an extrapolation of the A6 curve would indicate. A plot of the aim vs. final loading curve generated here and used for the Pewee 2 core extrusions is shown in Figure 4-3.

(CRD) The second problem, that of the loading taper, has not been completely explained. It is worst in the first element of the extrusion batch, and decrease after about half of the second element. A taper of five percent end-to-end was noted on one element. Experiments have been performed to understand this problem, but the results have not yet returned. For the purposes of Pewee 2, it was decided to simply relegate the first element of each batch to the extrusion tailings.

4.3 EXTRUDED CARBIDE TIPS (CRD)

(CRD) A developmental program was being conducted at the same time the TS-3016 program was being conducted to develop a method to extrude carbide tip stock. The carbide elements were extruded with Pewee I die pins so that the holes would not need reaming. The formulation of these elements was 75 w/o niobium carbide, 25 w/o POCO and thermax DCI, and 11.4 pph varcum binder. The elements were processed through the standard fuel element thermal cycle. The hole locations were so good that it was decided to braze 15 one-inch pieces cut from these elements to SX-5 fuel elements. Figure 4-4 illustrates the micro-structural difference between these tips and standard hot pressed composite tips. An attempt to break the as-brazed joints was unsuccessful, since the limit of the WNCO proof test rig is only 5000 psi. Several elements brazed with these tips passed the corrosion test.

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a) WNCO Extruded Composite
(400X)

b) WANL Hot Pressed
Composite (400X)

Figure 4-4. (CRD) Photomicrographs of WNCO Extruded (a) and WANL Hot Pressed (b)
75/25 NbC Graphite Composite Tip Material. (CRD)

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(CRD) It was necessary to heat treat the composite to 2500°C, rather than the standard fuel element treatment of 2200°C, to stabilize the carbide. The results of the physical properties tests on this material have not been received. However, so far the experiment is quite encouraging and a major saving in money for corrosion test tips has been accomplished.

4.4 METALLOGRAPHY (U)

(U) Figures 4-5 through 4-8 show 100X metallography of the Phase I and II elements. There is no obvious difference between the longitudinal and transverse direction. Neither is there any major difference in the appearance of elements made with the same flour and different binder levels. The figures do show a major difference in the appearance of the two flours. The AXM particle is a spongy, easily defined particle while the SX-5 particle resembles the standard Great Lakes flour particle.

(CRD) The above-mentioned figures illustrate how changes in loading effect the microstructures of the two materials. Little change is noted in the appearance of the SX-5 elements, while the AXM matrix is prone to fractures as the loading increases. These cracks have been tied to differences in CTE between the AXM flour and the fuel bead (α AXM flour $\sim 6.8 \times 10^{-6}$, at 2000°C, α fuel bead $\sim 3.8 \times 10^{-6}$ at 2000°C). This difference may generate as much as a 5000 psi tensile stress in the matrix on cooling from graph. These cracks have been loosely tied to increased leak rates at the higher AXM fuel loadings. This problem can be solved in one of two ways, a higher expansion bead, or a bead matrix interface gap at graph temperature which would close at room temperature.

4.5 LEAK RATE (U)

(CRD) Table 4.1 summarizes the leak rate data gathered on the TS-3016 elements. All data is reported for elements in the as-machined condition. As expected, the standard combination of 85 pph flour to 15 pph thermax did not give acceptable leak rates. The SX-5 elements made with 18% thermax gave the best results and these results were proven valid with the Phase II extrusions.

630-1047449 (L) 30% Binder
15% Thermax (AXM)

630-1047449 (L) 30% Binder
15% Thermax (AXM)

630-1047465 (L) 31% Binder
15% Thermax (AXM)

630-1047464 (L) 31% Binder
15% Thermax (AXM)

243-1047472 (L) 30% Binder
15% Thermax (AXM)

243-1047474 (L) 30% Binder
25% Thermax (AXM)

243-1047478 (L) 31% Binder
15% Thermax (AXM)

243-1047487 (L) 31% Binder
15% Thermax (AXM)

630-1047449 (T) 30% Binder
15% Thermax (AXM)

630-1047464 (L) 31% Binder
15% Thermax (AXM)

630-1047465 (T) 31% Binder
15% Thermax (AXM)

630-1047464 (T) 31% Binder
15% Thermax (AXM)

243-1047472 (T) 30% Binder
15% Thermax (AXM)

243-1047474 (T) 30% Binder
15% Thermax (AXM)

243-1047478 (T) 31% Binder
15% Thermax (AXM)

243-1047478 (T) 31% Binder
15% Thermax (AXM)

Figure 4-5 (CRD) Metallography of The Phase I, TS-3016 AXM Fuel Elements (U)
(Shown are changes in microstructure with changes in loading. Top series from Transverse
mounts; bottom from longitudinal mounts.)

Figure 4-6 (CRD) Metallography of The Phase II, TS-3016 AXM Fuel Elements
As A Function of Loading (U) (U)
(Shown are changes in microstructure with changes in loading. Top series from transverse
mounts; bottom series from longitudinal mounts.)

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630-1047139 (L) 24% Binder
15% Thermax (SX5)

630-1047149 (L) 25% Binder
15% Thermax (SX5)

630-1047161 (L) 24% Binder
18% Thermax (SX5)

630-1047173 (L) 23.5% Binder
23% Thermax (SX5)

630-1047183 (L) 24% Binder
15% Thermax, Sized SX5

630-1047192 (L) 27.5% Binder
15% Thermax (GLF)

630-1047139 (T) 24% Binder
15% Thermax (SX5)

630-1047149 (T) 25% Binder
15% Thermax (SX5)

630-1047161 (T) 24% Binder
18% Thermax (SX5)

630-1047173 (T) 23.5% Binder
23% Thermax (SX5)

630-1047183 (T) 24% Binder
15% Thermax, Sized SX5

630-1047192 (T) 27.5% Binder
15% Thermax (GLF)

Figure 4-7 (CRD) Metallography of The Phase I, TS-3016 SX-5 and GLF Fuel Elements (U)
(Shown are changes in Microstructure with changes in loading. Top series from transverse
mounts; bottom from longitudinal mounts.)

Figure 4-8 (CRD) Metallography of The Phase II, TS-3016 SX-5 Fuel Elements As A Function of Loading (U)
(Shown are changes in microstructure with changes in loading. Top series from transverse mounts; bottom from longitudinal mounts.)

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(CRD) The AXM elements presented a different problem. The low loadings did not show high leak rates. The 630's were generally bad. However, when the process was changed from 30 to 28% binder to lower the leak rate, the average was actually raised 100 cc/min. The experimental Phase II batches made with 18% thermax were good, averaging 88 cc/min. The 27% binder elements averaged 144 cc/min. The baseline Phase II 28% binder elements averaged 356 cc/min.

(CRD) Note the trend to increasing leak rate as the loading increases. This has been a problem with all types of flour. It indicates a skewing of the matrix particle size distribution with increases in loading. In a 630 loaded element, the solid volume is about 20% fuel beads. There is need, therefore, for a special blend of flour for each loading code to minimize element permeability. Some work has been done in this area with limited success. When this was tried with SX-5 (Table 3.2), the results showed a slight decrease in leak rate, but this was a preliminary effort. The addition of 18 and 23% thermax was also an attempt at this. Apparently, 18% was not enough and 23% was too much fine material for the SX-5 with its particular starting distribution.

4.6 PHYSICAL PROPERTIES (U)

4.6.1 Coefficient of Thermal Expansion (U)

(CRD) The CTE measurements on the TS-3016 elements were made by the WANL Thermophysical Properties Laboratory. Longitudinal samples were from the gas end and the approximate middle of the elements. Transverse samples were taken from positions adjacent to the longitudinal samples. The longitudinal samples were full cross sections, 3.01 ± 0.005 inches long. Transverse samples were a group of four, 1/4 inch long wafers, cemented flat to flat to make a three inch long specimen. All data was measured on machined, unleached samples.

(U) Table 4.2 lists the CTE, both longitudinal and transverse, for the SX-5 and AXM elements tabulated as a function of loading and matrix. Figures 4-9 and 4-10 show typical curves for these materials. Some problem was noted in measuring consistent values

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TABLE 4-1 (CRD) LEAK RATE SUMMARY (U) TS-3016

<u>F flour</u>	<u>Load</u>	<u>DCI Ratio</u>	<u>Binder Level</u>	<u>As-Mach. Average Leak Rate</u>	<u>Range</u>	<u>Qty.</u>	<u>Use</u>
AXM	630	85/15	30	267	125-840	28	Coating Qual. and Stress
AXM	521	85/15	30	201	130-225	5	Stress
SX-5	630	82/18	24	126	49-230	30	Coating Qual. and Stress
SX-5	521	82/18	24	38	15-58	4	Stress
AXM	630	85/15	28	356	195-495	11	Q. C. Std.
AXM	630	82/18	28	88	62-130	5	Q. C. Std.
AXM	630	85/15	27	144	100-280	10	Engr. Dev. and Q. C. Std.
SX-5	166	82/18	24	39	18-70	3	Q. C. Std.
SX-5	200	82/18	24	26	----	1	Q. C. Std.
SX-5	243	82/18	24	24	----	1	Q. C. Std.
SX-5	267	82/18	24	44	----	1	Q. C. Std.
SX-5	293	82/18	24	71	----	1	Q. C. Std.
SX-5	355	82/18	24	32	----	1	Q. C. Std.
SX-5	430	82/18	24	175	----	1	Q. C. Std.
SX-5	521	82/18	24	63	----	1	Q. C. Std.
AXM	000	85/15	28	58	----	1	Q. C. Std.
AXM	166	85/15	28	43	14-59	4	Q. C. Std.

TABLE 4-1 (CRD) LEAK RATE SUMMARY (U) TS-3016 (CONTINUED)

<u>Flour</u>	<u>Load</u>	<u>DCI Ratio</u>	<u>Binder Level</u>	<u>As-Mach. Average Leak Rate</u>	<u>Range</u>	<u>Qty.</u>	<u>Use</u>
AXM	200	85/15	28	42	- - - -	1	Q. C. Std.
AXM	243	85/15	28	55	- - - -	1	Q. C. Std.
AXM	267	85/15	28	115	- - - -	1	Q. C. Std.
AXM	293	85/15	28	29	- - - -	1	Q. C. Std.
AXM	355	85/15	28	137	100-175	2	Q. C. Std.
AXM	391	85/15	28	120	- - - -	1	Q. C. Std.
AXM	430	85/15	28	155	- - - -	1	Q. C. Std.
AXM	521	85/15	28	113	62-235	8	Q. C. Std.
AXM	573	85/15	28	275	- - - -	1	Q. C. Std.
SX-5	391	82/18	24	62	- - - -	1	Q. C. Std.
SX-5	573	82/18	24	75	- - - -	1	Q. C. Std.

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TABLE 4-2

(CRD) COEFFICIENT OF THERMAL EXPANSION DATA ON THE TS-3016 FUEL ELEMENTS (U)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>CTE (L) % at 2000°C</u>	<u>CTE (L) x 10⁶ at 2000°C</u>	<u>CTE (T) % at 2000°C</u>	<u>CTE (T) x 10⁶ at 2000°C</u>
<u>PHASE I</u>					
SX-5 (85/15-24%)	630	0.98	4.90	1.08	5.40
SX-5 (85/15-25%)	630	0.98	4.90	1.08	5.40
SX-5 (82/18-24%)	630	1.02	5.15	1.18	6.00
SX-5 (77/23-23.5%)	630	0.97	4.88	1.12	5.70
SX-5 (sized) (85/15-24%)	630	0.97	4.88	---	---
GLF (85/15-27.5%)	630	0.73	3.69	---	---
AXM (85/15-30%)	630	1.15	5.80	---	---
AXM (85/15-31%)	630	1.15	5.80	---	---
AXM (85/15-30%)	243	1.22	6.20	---	---
AXM (85/15-31%)	243	1.22	6.20	---	---
<u>PHASE II</u>					
SX-5 (82/18-24%)	630	1.00 1.01	5.05 5.10	1.08 1.12	5.40 5.55
SX-5 (82/18-24%)	573	1.03	5.25	1.18	5.95

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TABLE 4-2

(CRD) COEFFICIENT OF THERMAL EXPANSION DATA ON THE TS-3016 FUEL ELEMENTS (U)
(CONTINUED)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>CTE (L) % at 2000°C</u>	<u>$\bar{\alpha} \times 10^6$ CTE (L) at 2000°C</u>	<u>CTE (T) % at 2000°C</u>	<u>$\bar{\alpha} \times 10^6$ CTE (T) at 2000°C</u>
<u>PHASE II (Cont'd)</u>					
SX-5	430	1.08	5.45	1.22	6.15
(82/18-24%)		1.05	5.35	1.12	5.75
SX-5	355	1.05	5.35	1.28	6.45
(82/18-24%)		1.06	5.40	1.25	6.26
SX-5	293	1.08	5.45	1.20	6.10
(82/18-24%)		1.08	5.45	1.13	5.74
SX-5	243	1.10	5.60	1.28	6.48
(82/18-24%)		1.09	5.55	1.18	6.00
SX-5	200	1.11	5.65	1.24	6.21
(82/18-24%)		1.06	5.40	1.25	6.27
SX-5	000	---	---	---	---
(82/18-24%)		---	---	---	---
AXM	630	1.12	5.60	1.17	5.90
(85/15-28%)		1.12	5.60	1.14	5.70
AXM	630	1.18	6.00	---	---
(82/18-28%)		1.21	6.10	---	---
AXM	630	---	---	---	---
(85/15-27%)		---	---	---	---
AXM	573	1.16	5.82	1.09	5.60
(85/15-28%)		1.21	6.11	1.17	5.85
AXM	355	1.20	6.10	1.20	6.10
(85/15-28%)		1.21	6.12	1.25	6.40
AXM	293	1.18	6.00	1.17	5.90
(85/15-28%)		1.22	6.15	1.22	6.15

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TABLE 4-2

(CRD) COEFFICIENT OF THERMAL EXPANSION DATA ON THE TS-3016 FUEL ELEMENTS (U)
(CONTINUED)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>CTE (L) % at 2000°C</u>	<u>CTE (L) $\times 10^6$ at 2000°C</u>	<u>CTE (T) % at 2000°C</u>	<u>CTE (T) $\times 10^6$ at 2000°C</u>
<u>PHASE II (Cont'd)</u>					
AXM	243	1.19	6.10	1.27	6.38
(85/15-28%)		1.19	6.10	1.24	6.25
AXM	200	1.23	6.30	1.32	6.65
(85/15-28%)		1.25	6.40	1.25	6.40
AXM	000	---	---	---	---
(85/15-28%)		---	---	---	---
AXM	430	1.24	6.22	1.22	6.15
(85/15-28%)		1.22	6.15	1.22	6.15

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Figure 4-9. (CRD) Typical CTE Curve For The Phase II TS-3016 AXM Fuel Elements. (U)

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Figure 4-10. (CRD) Typical CTE Curve For The Phase II TS-3016 SX-5 Fuel Elements. (U)

(U) on the transverse samples. As yet, this difficulty is unexplained. The longitudinal samples show relative consistency, the highest loadings having the lower CTE values. This trend in CTE with loading is normal for NERVA extruded fuel.

(CRD) Small changes in binder level do not effect a major change in CTE for these materials. However, in going from 31 to 28% binder level on 630 loaded AXM elements, the CTE ($\bar{\alpha}$) went from 5.80 to 5.60. Changing the thermax level from 15 to 18% raised the CTE on 630 loaded SX-5's from 4.90 to 5.10 and from 5.60 to 6.00 on 630 loaded AXM's. The peculiar shape of the AXM curve is not completely explained. This phenomenon is being investigated more fully.

4.6.2 Elevated Temperature Thermal Conductivity (U)

(CRD) Thermal conductivity was measured on a five-inch specimen turned from the full hex down to a 1/2-inch seven holed cylinder. The values were measured on as-reamed, unleached samples. The data is somewhat surprising in that it is considerably higher than the low expansion material. Note in Table 4-3 in particular the difference between SX-5 630 loaded element and the A6 fuel element, added for comparison. These data are somewhat in conflict with theory which would poorly predict that the graphitized, high expansion flour should have low thermal conductivities. The WANL standard was rerun several times during the testing of these samples, each time reconfirming previous measurements. This tends to verify the equipment and procedure and appears to confirm the measurements.

4.7 MECHANICAL PROPERTIES (U)

(U) Table 4-4 lists the mechanical properties measured on the Phase I and II TS-3016 elements. All measurements were made on as-machined, unleached samples. Only one element per loading flour type was available for sampling due to a shortage of fuel elements. The Phase I data represents an average of three samples. All available data is reported on the Phase II elements.

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TABLE 4-3

(CRD) ELEVATED TEMPERATURE THERMAL CONDUCTIVITY ON THE PHASE II, TS-3016 FUEL ELEMENTS (U)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>Mean Temp. (°C)</u>	<u>Conductivity BTU/Hr. Ft. °F</u>
SX-5 (82/18 - 24%)	630	1612	26.11
		1717	26.47
		1820	26.60
SX-5 (82/18 - 24%)	200	1629	30.22
		1736	29.37
		1802	28.99
AXM (82/18 - 28%)	630	1604	23.87
		1717	24.53
		1799	23.73
AXM (82/18 - 28%)	630	1634	26.92
		1732	26.44
		1811	25.96
AXM (85/15 - 28%)	573	1630	23.91
		1717	24.86
		1801	24.29
AXM (85/15 - 28%)	430	1675	23.02
		1771	22.91
		1861	23.73
AXM (85/15 - 28%)	355	1659	24.37
		1748	25.31
		1818	26.27
AXM (85/15 - 28%)	293	1642	28.03
		1723	27.04
		1793	26.59

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TABLE 4-3

(CRD) ELEVATED TEMPERATURE THERMAL CONDUCTIVITY ON THE PHASE II TS-3016 FUEL ELEMENTS (U)

(CONTINUED)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>Mean Temp. (°C)</u>	<u>Conductivity BTU/Hr. Ft. °F</u>
AXM (85/15 - 28%)	243	1643 1732 1812	28.67 27.71 28.24
AXM (85/15 - 28%)	200	1621 1723 1808	29.02 28.59 29.75
AXM (85/15 - 28%)	000		
A-6 Fuel GLF (85/15 - 27%)	460	1921	18.80
A-6 Fuel GLF (85/15 - 27%)	000	1890	20.20

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TABLE 4-4 (CRD) MECHANICAL PROPERTIES: TS-3016 ELEMENTS (U)

<u>Matrix</u>	<u>Loading</u>	<u>Flexure Strength (RT - PSI)</u>	<u>Compressive Strength (RT - PSI)</u>	<u>Flexure Strength (2200°C - PSI)</u>	<u>Sonic Modulus (RT - PSI x 10⁻⁶) (L/T)</u>
<u>Phase I</u>					
SX-5 (85/15-24%)	630	4,100	12,970	NA	1.5/1.8
SX-5 (85/15-25%)	630	4,240	13,160	NA	1.5/1.8
SX-5 (82/18-24%)	630	3,820	13,600	NA	1.5/1.8
SX-5 (77/23-23.5%)	630	3,910	11,790	NA	1.5/1.8
SX-5(sized) (85/15-24%)	630	4,080	12,080	NA	1.5/1.9
GLF (85/15-27.5%)	630	4,230	11,150	NA	NA
AXM (85/15-30%)	630	3,000	15,000	NA	NA
AXM (85/15-31%)	630	3,700	14,000	NA	NA

TABLE 4-4 (CRD) MECHANICAL PROPERTIES: TS-3016 ELEMENTS (U) (CONTINUED)

<u>Matrix</u>	<u>Loading</u>	<u>Flexure Strength (RT - PSI)</u>	<u>Compressive Strength (RT - PSI)</u>	<u>Flexure Strength (2200°C - PSI)</u>	<u>Sonic Modulus (RT - PSI x 10⁻⁶) (L/T)</u>
AXM (85/15 - 30%)	243	3,700	17,500	NA	NA
AXM (85/15 - 31%)	243	3,900	16,600	NA	NA
<u>Phase II</u>					
AXM (85/15 - 28%)	630	3,640	14,120	6,850	1.5/1.5
		4,750	12,810		
		3,660	13,340		
AXM (82/18 - 28%)	630	2,970	14,040	8,630	1.7/1.7
		4,500	14,730		
		3,770	15,300		
AXM (85/15 - 27%)	630	4,300	10,770		
		4,170	11,670		
		3,430	11,070		
AXM (85/15 - 28%)	573	4,030	13,020	8,140	1.6/1.6
		4,060	13,340		
		3,540	13,050		
AXM (85/15 - 28%)	430	3,660	13,940	9,070	1.7/1.7
		4,200	14,300		
		4,800	14,210		

TABLE 4-4 (CRD) MECHANICAL PROPERTIES: TS-3016 ELEMENTS (U) (CONTINUED)

Matrix	Loading	Flexure Strength (RT - PSI)	Compressive Strength (RT - PSI)	Flexure Strength (2200°C - PSI)	Sonic Modulus (RT - PSI x 10 ⁻⁶) (L/T)
AXM (85/15 - 28%)	355	4,530 4,140 4,270	15,800 14,400 12,300	8,220	1.7/1.6
AXM (85/15 - 28%)	293	5,020 4,910 4,380	9,840 17,050 16,000	6,700	1.6/1.6
AXM (85/15 - 28%)	243	5,200 5,240 4,070	14,480 16,580 15,560	7,550	1.6/1.6
AXM (85/15 - 28%)	200	4,620 4,620 4,660	16,820 18,930 16,280	10,250	1.6/1.6
AXM (85/15 - 28%)	000	5,780 5,530 5,700	16,340 16,000 16,250	NA	NA
SX-5 (82/18 - 24%)	630	4,630 4,480 4,840	14,660 12,210 14,540	7,000	NA/1.9
SX-5 (82/18 - 24%)	573	5,070 4,480 3,490	14,420 14,300 15,980	8,880	1.5/1.9

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TABLE 4-4 (CRD) MECHANICAL PROPERTIES: TS-3016 ELEMENTS (U) (CONTINUED)

<u>Matrix</u>	<u>Loading</u>	<u>Flexure Strength (RT - PSI)</u>	<u>Compressive Strength (RT - PSI)</u>	<u>Flexure Strength (2200°C - PSI)</u>	<u>Sonic Modulus (RT - PSI x 10⁻⁶) (L/T)</u>
SX-5 (82/18-24%)	430	4,210	14,780	6,930	1.8/1.9
		4,200	13,280		
		3,880	14,540		
SX-5 (82/18-24%)	355	4,280	16,340	10,325	1.8/1.9
		4,090	15,320		
		4,520	14,660		
SX-5 (82/18-24%)	293	3,860	14,060	6,560	1.5/1.9
		3,700	13,040		
		4,480	15,440		
SX-5 (82/18-24%)	243	4,950	15,680	6,790	1.5/1.9
		4,110	14,990		
		4,110	14,420		
SX-5 (82/18-24%)	200	4,950	16,930	8,160	1.5/1.9
		4,340	16,520		
		4,810	16,400		
SX-5 (82/18-24%)	000	6,730	17,060	NA	NA
		5,980	19,200		
		6,570	16,790		

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- (CRD) The room temperature flexure strength was measured on a four and one half (4-1/2) inch long specimen with a one, two, one inch span between load points. Of interest is the general decrease in strength with increases in loading. This is normal for NERVA fuel elements. The average values are also normal for varcum bound elements. The spread in the results on the AXM elements is abnormal. The reason for this behavior is not yet understood. It may be linked, however, to the bead-related, matrix cracks discussed in the metallography section.
- (CRD) Compressive strength was measured on a one-inch specimen, crushed axially. While compressive strength is not considered a prime criterion for quality in a fuel element, two points are noted. The high expansion flours tend to be stronger in compression than the standard Great Lakes flour. Also, the same trend to low strength with high loadings noted in flexure testing is seen in compressive testing.
- (U) The 2200°C flexure testing was done on a 1.75 inch specimen in three point loading, due to equipment limitations. This test was done instead of a tensile test because a satisfactory procedure for elevated temperature tensile testing has not been developed. The fact that a three-point test was made on one sample per type shades the data to the point where it will only be presented for use as a baseline. A satisfactory tensile test is being developed, and this data will be generated as soon as possible.
- (U) Sonic modulus tests were run at Y-12 on five inch long full cross sections.
- (CRD) Some points can be made concerning the reported data. The AXM elements tend to be more isotropic than the SX-5 elements. Loading variations do not significantly effect the measured values for either flour.
- (CRD) It is hypothesized that the varcum binder and the thermax level so influence the bulk modulus that small changes due to changes in flour type are washed out either by the binder phase or the test itself. Numbers of the order of 40×10^6 have been presented as a typical modulus for coked varcum. If this is a good value, the above hypothesis may be realistic since the varcum thermax phase is the continuous phase.

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4.8 MISCELLANEOUS DATA (U)

(CRD)

Table 4-5 lists the room temperature resistance, bulk density, and calculated carbon density for the TS-3016 fuel elements. Bulk density was measured by the wax displacement method on three quarter inch long full cross sections in the as-machined, unleached condition. Calculated carbon density was determined by subtracting the gamma scan uranium loading from the measured bulk density value. The room temperature resistance was measured on a two-inch, full cross section span. Data is reported on the Phase II elements only. Note that the SX-5 matrix has a higher density than the AXM. Note also the change in calculated carbon density with loading. The change in carbon density with loading is not unusual for NERVA fuel elements.

(U)

The room temperature resistance data illustrates the fact that the high expansion flours are generally less graphitic, and, hence, have higher resistances than the low expansion flour. Some attempts have been made to directly relate the room temperature resistance to the CTE, but insufficient data is, as yet, available to derive this empiried relationship.

4.9 CORROSION TESTING (U)

(U)

A detailed analysis of the corrosion test performance of the TS-3016 elements is beyond the scope of this report because of the effect of coating structure and type on the corrosion test. However, the results of several tests on the 3016 elements are listed for comparison.

(CRD)

The AXM elements tend to lose less weight and stand up to cycling better than the SX-5 elements. Both types tend to out perform the GLF elements. The comparison data is shown in Table 4-6 .

4.10 THERMAL STRESS TESTING (U)

(U)

The thermal stress data generated on the Phase I elements only will be reported here. The data was so interesting that it prompted a much larger, more specialized plan for the Phase II elements. The data on the Phase II elements will be presented in a separate report.

TABLE 4-5

(CRD) DENSITY AND RESISTANCE VALUES FOR THE TS-3016 ELEMENTS (U)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>Bulk Density (g/cc)</u>	<u>Calc. Carbon Density (gc/cc)</u>	<u>RT Resis. (milliΩ/in.)</u>
AXM (85/15-28%)	630	2.448 2.449	1.784 1.785	3.14
AXM (82/18-28%)	630	2.456 2.441	1.788 1.773	3.23
AXM (85/15-27%)	630	2.427 2.423		3.08
AXM (85/15-28%)	573	2.391 2.389		3.23
AXM (85/15-28%)	430	2.256 2.258		2.96
AXM (85/15-28%)	355	2.200 2.198		2.92
AXM (85/15-28%)	293	2.140 2.139		2.83
AXM (85/15-28%)	243	2.095 2.097		2.78
AXM (85/15-28%)	200	2.056 2.055		2.75
AXM (85/15-28%)	000	1.870 1.873	1.870 1.873	2.40
SX-5 (82/18-24%)	630	2.483 2.480		2.44

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TABLE 4-5 (Cont'd)

(CRD) DENSITY AND RESISTANCE VALUES FOR THE TS-3016 ELEMENTS (U)

<u>Matrix</u>	<u>Loading (mg U/cc)</u>	<u>Bulk Density (g/cc)</u>	<u>Calc. Carbon Density (gc/cc)</u>	<u>RT Resis. (milli /in.)</u>
SX-5 (82/18-24%)	573	2.435 2.436		2.13
SX-5 (82/18-24%)	430	2.303 2.304		2.10
SX-5 (82/18-24%)	355	2.239 2.238		1.96
SX-5 (82/18-24%)	293	2.185 2.180		1.97
SX-5 (82/18-24%)	243	2.142 2.140		1.88
SX-5 (82/18-24%)	200	2.097 2.098		1.99
SX-5 (82/18-24%)	000	1.915 1.913		1.86

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TABLE 4-6 (CRD) R1.09 CORROSION TEST DATA OF THE TS-3016 ELEMENTS (U)

Serial Number	Test No.	Time (min.)	Gross ΔW (gms)	Pin Holes*/Mule Wt. Loss			Comments
				0-25	25-50	0-52	
SX-5							
630-1047140 (85/15-24%)	1.2928	2 x 10 + 4.0	5.2	0/0.53	0/3.67	2/7.12	Bore exposed at 51-3/8 - 51-5/8. Seal at wrong location.
630-1047143 (85/15-24%)	1.2918	3.8 + 3.2	15.5	0/0.10	1/15.47	2/15.57	Lost seal at 3.8. Broke 48-1/2" with corr. pocket.
630-1047144 (85/15-24%)	1.3034	10 + 8.5 + 11.5 + 10 + 7.0	14.2	0/0.80	72/10.37	13/12.42	Lost seal 8.5 + 7.0. Broke on ramp at 48".
630-1047146 (85/15-24%)	1.3026	10 + 5 + 15 + 10 + 6	9.6	0/0.62	0/5.79	5/7.95	Lost seal at 5.
630-1047150 (85/15-25%)	1.2945	10 + 1.0	17.8	0/0.17	1/16.45	0/16.61	Broke at 45-1/4 corr. pocket. Ch. 10 partially blocked.
630-1047154 (85/15-25%)	1.2958	6.2	2.5	0/0	0/0	0/0	Broke with excessive bow 2-1/2, 14-1/2, 26, 29-1/4, 49.
630-1047155 (85/15-25%)	1.2952	10 + 3.5	16.8	0/0.23	6/15.18	2/15.41	Lost DP.
630-1047162 (82/18-24%)	1.2921	3.8 + 4.3 + 21.9 + 10 + 3.3	8.1	0/0.79	0/6.07	0/7.27	Lost seal 3.8 + 4.3. Chuck cracked 3.3.
630-1047162 (82/18-24%)	1.2963	2.0	4.3	0/0.52	0/7.28	0/12.59	Broke 51-5/8 mech. Corr. 51 - 51-5/8.

* Pin hole location 0-25, 25-48, 48-52.

TABLE 4-6 (CRD) R1.09 CORROSION TEST DATA OF THE TS-3016 ELEMENTS (U) (CONTINUED)

Serial Number	Test No.	Time (min.)	Gross ΔW (gms)	Pin Holes*/Mule Wt. Loss			Comments
				0-25	25-50	0-52	
SX-5							
630-1047168 (82/18-24%)	1.2960	2 x 10 + 3.5 + 16.5 + 3.5	9.6	2/0.16	6/7.33	0/8.37	Lost seal 3.5 cycle 3. Lost DP 3.5 cycle 5.
630-1047167 (82/18-24%)	1.2938	3 x 10 + 0.1 + 6.0	7.2	2/0.33	7/5.09	0/6.54	Lost seal 0.1, lost DP 6.0. 9 PH 30 - 40.
630-1047171 (85/15-24%)	1.3016	4.1	1.1	0/0	0/0	0/0	Broke 15-1/4, 49 mech.
630-1047188 (85/15-24%)	1.2965	10 + 4.5	9.8	3/0.15	0/9.81	0/10.04	Broke 46-1/4 arc.
630-1047189 (85/15-24%)	1.2979	10 + 1.7	15.2	0/0.32	4/14.12	0/14.34	Broke at 47-3/4 corr.
GLF							
630-1047193 (85/15-27.5%)	1.2942	10	12.2	0/0.36	2/10.77	2/11.28	Broke at 45-1/8 corr. pocket.
630-1047198 (85/15-27.5%)	1.2973	10 + 3.5	11.2	0/0.37	6/11.82	0/12.30	Broke at 45-3/8 unloading corr. pocket.
630-1047199 (85/15-27.5%)	1.2997	10 + 8.0	4.8	0/0.33	1/4.24	2/4.61	Lost DP.
630-1047197 (85/15-27.5%)	1.2935	2 x 10 + 3.5	9.6	0/0.54	1/8.82	0/9.63	Rechuck after cycle 2. Broke at 46 corr. pocket.

* Pin hole location 0-25, 25-48, 48-52.

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TABLE 4-6 (CRD) RI.09 CORROSION TEST DATA OF THE TS-3016 ELEMENTS (U) (CONTINUED)

Serial Number	Test No.	Time (min.)	Gross ΔW (gms)	Pin Holes*/Mule Wt. Loss			Comments
				0-25	25-50	0-52	
GLF (Cont'd)							
630-1047203 (85/15-27.5%)	1.2937	10 + 1.0	12.6	0/0.09	17/12.01	7/12.22	Broke at 48-1/4 corr. pocket. Surf. corr. 47 - 49.
AXM							
630-1047446 (85/15-30%)	1.3017	0	3.1	0/0	0/0	0/0	Broke at 2-3/4 arc; 4-1/8, 25-1/2, 38-3/8, 44 mech.
630-1047451 (85/15-30%)	1.3018	1.4	5.8	0/0	0/0	0/0	Broke at 3.22 arc; 43-3/4, 48-1/2 mech.
243-1047468 (85/15-30%)	1.2936	5.2	6.4	0/1.14	0/1.44	0/2.64	Broke 31 corr; 4-3/4, 8-1/4, 39-7/8, 48-3/4 arc; cracks 4 - 39.
243-1047471 (85/15-30%)	1.2939	4 x 10 + 4.2 + 13	15.4	0/0.69	59/11.02	1/13.33	Cold break at 51, lost seal at 42, surf. corr. 31 - 49-1/4.
243-1047475 (85/15-30%)	1.2919	1.7	3.2	0/0	0/0	0/0	Broke 5-7/8 arc; 8-3/4, 45 mech.
243-1047476 (85/15-30%)	1.2957	0	2.9	0/0	0/0	0/0	Broke 5-7/8 arc; cracks 4 - 15.

* Pin hole location 0-25, 25-48, 48-52.

TABLE 4-6 (CRD) R1.09 CORROSION TEST DATA OF THE TS-3016 ELEMENTS (U) (CONTINUED)

Serial Number	Test No.	Time (min.)	ΔW (gms)	Pin Holes*/Mule Wt. Loss			Comments
				0-25	25-50	0-52	
AXM (Cont'd)							
243-1047477 (85/15-30%)	1.3015	2.9	5.1	0/0	0/0	0/0	Broke at 7, corr; 4-1/2, 47-3/4 mech.
243-1047480 (85/15-31%)	1.2922	3 x 10 + 5.5 + 14.5 + 10	14.7	0/0.40	0/10.00	4/10.99	Replace chuck 5.5.
243-1047482 (85/15-31%)	1.2950	3 x 10 + 4.2 + 5.8 + 10	12.5	0/0.73	0/7.30	0/8.76	Lost seal 4.2; lost DP 50, bores exposed 51 - 51-5/8.
243-1047483 (85/15-31%)	1.2940	4.2 + 6.0 + 19.8 + 2 x 10 + 8.0	7.8	1/0.32	0/4.16	0/5.03	
243-1047484 (85/15-31%)	1.2954	3 x 10 + 3.5 + 16.5 + 8	12.4	0/0.43	1/8.87	2/10.55	Lost seal 3.5; lost DP 8.0.
243-1047486 (85/15-31%)	1.2961	3 x 10 + 1.0 + 19 + 1.7	13.0	0/0.03	6/8.93	0/9.40	Lost seal 1.0; lost DP 1.7.
243-1047488 (85/15-31%)	1.2987	2 x 10 + 5.3 + 14.7 + 2 x 10	12.4	0/0.08	2/9.23	0/10.28	Lost seal 5.3.
243-1047489 (85/15-31%)	1.3012	6 x 10	35.4	0/0.12	95/27.29	19/29.07	Surface corr. 40 - 49.

* Pin hole location 0-25, 25-48, 48-52.

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(CRD) Two of each type of the SX-5 Phase I elements were coated along with two GLF elements (12 elements total, all 630 loaded) in WNCO GEM NbC run C442. This run was aborted before the full run time was accomplished. An attempt was made to obtain a flat, uniform 0.5 mil coat for stress testing. Weight gains on these elements indicated that this might have been accomplished. It was, therefore, decided to split the elements into two groups (one of each type per group), ship group I to LASL as-coated, and recoat group II in C444 to complete the original run plan. Group II was then shipped to LASL.

(CRD) The AXM elements were all coated in NbC GEM run L328. This run was planned as a base coat for a ZrC-HED run, and has the characteristic profile of this type of run. These elements were then shipped to LASL.

(CRD) Three samples were taken from each element. Each sample was $14^{+0.5}_{-0.0}$ inches long. Sample one came from station 3 to station 17, sample 2 from approximately station 17 to 31, and sample 3 from approximately 31 to 45. The cold end was maintained in each sample. PDE and beta backscatter were obtained on all elements prior to sectioning. The individual element coating and resistance profiles and test results are presented in Figures 4-11 through 4-30.

(CRD) The data generated in the Phase I testing is inconclusive. It illustrates that as a class the high expansion elements have characteristically lower thermal stress failure resistance than do the low expansion elements. It also illustrates that some feature of the coating (i.e., thickness, profile, resistance, structure, roughness, or a combination of these properties) has a very strong effect on the absolute value obtained in the LASL N-7 thermal stress test rig. The relatively flat, thin, uniform coating obtained in C442 gave somewhat uniform bulk failure power numbers. The coating obtained from run combination C442/C444 gave a quite different response in the LASL test. Several attempts have been made to correlate the relative values obtained on these samples to such variables as coated resistance profiles, slope of the coating profile, and absolute coating thickness; but these attempts have led to frustration.

(U) With these difficulties, one cannot determine from the N-7 test the true matrix, thermal stress resistance.

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(CRD) Figure 4-11. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047141 (U)

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(CRD) Figure 4-12. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047142 (U)

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(CRD) Figure 4-13. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047151 (U)

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(CRD) Figure 4-14. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047152 (U)

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(CRD) Figure 4-15. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047163 (U)

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(CRD) Figure 4-16. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047164 (U)

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(CRD) Figure 4-17. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047175 (U)

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(CRD) Figure 4-18. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047176 (U)

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(CRD) Figure 4-19. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047185 (U)

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(CRD) Figure 4-20. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047186 (U)

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(CRD) Figure 4-21. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047194 (U)

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(CRD) Figure 4-22. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047195 (U)

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(CRD) Figure 4-23. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047443 (U)

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(CRD) Figure 4-24. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047445 (U)

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(CRD) Figure 4-25. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047455 (U)

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(CRD) Figure 4-26. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 630-1047457 (U)

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(CRD) Figure 4-27. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 243-1047467 (U)

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(CRD) Figure 4-28. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 243- 1047469 (U)

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(CRD) Figure 4-29. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 243-1047479 (U)

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(CRD) Figure 4-30. β -Backscatter Coating Profile, Incremental Resistance, and Bulk Fracture Power at Failure on Element No. 243-1047481 (U)

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5.0 DISCUSSION OF RESULTS (U)

(U) The data gathered to this point on the TS-3016 elements shows that these elements tend to differ from A6 reactor vintage elements in three areas. They are higher in expansion. They, consequently, have poorer thermal stress resistance. They also tend to be more isotropic.

(U) The objectives of TS-3016 appear to have been adequately satisfied. The AXM matrix has been adequately characterized in all aspects except for high temperature mechanical property data. This will be obtained. The thermal stress resistance of these elements is lower than desired, but should be adequate for the needs of Pewee 2. With more engineering effort, the baseline Pewee 2 matrix can be made to meet the objectives of the R-1 fuel element as they are now understood. A tremendous amount of property data was generated on this family of elements, and some sampling is still being done.

(U) It is felt that the effect of the matrix cracks observed in these elements cannot be overstated. These flaws would tend to deteriorate almost every property measured from leak rate clear through to the value obtained in the thermal stress rig. If these cracks could be driven from the matrix, the elements would be much more attractive as core candidates.

(CRD) The corrosion test data, while not reported in detail here, has shown some quite favorable results. Sixty minute cyclic tests on these elements are no longer uncommon. Neither are weight losses of less than ten (10) grams in 60 minutes. While the corrosion mechanism of the HCTE fuel is different than that of GLF materials, it is well under control.

(U) It appears that the only area which has not been adequately covered is the thermal stress problem and the properties which must be measured to make the model complete for analysis. This area is being pursued vigorously both at WNCO and WANL. If these elements can pass a well-defined and understood thermal stress test, they will receive a strong endorsement for use both in Pewee 2 and in R-1.

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