CONFIDENTIAL

MASTER

UNCLASSIFIED

QUARTERLY PROGRESS REPORT
FUELED GRAPHITE STUDIES
JULY, AUGUST, SEPTEMBER 1968

JANUARY, 1969

AEC RESEARCH &
DEVELOPMENT REPORT

Exempt from CCRP Re-review Requirements *NA 3/21/05*
(per 7/22/82 Duff/Caudle memorandum)

Classification cancelled for change to

by authority of *Doc*

by *H. J. Canell*, TIC, date *AUG 28 1973*

~~RESTRICTED DATA~~

~~THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED
IN THE ATOMIC ENERGY ACT OF 1954. ITS TRANSMITTAL OR
THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER TO AN
UNAUTHORIZED PERSON IS PROHIBITED.~~

68 9765

~~CONFIDENTIAL~~

~~DISTRIBUTION OF THIS DOCUMENT IS LIMITED
To Government Agencies and their Contractors - CAP~~

BATTELLE
BATTELLE MEMORIAL INSTITUTE
BATTELLE BOULEVARD, P. O. BOX 999, RICHLAND, WASHINGTON 99352

NORTHWEST
PACIFIC NORTHWEST LABORATORY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

BNWL-934

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~CONFIDENTIAL~~

INFORMATION CONCERNING USE OF THIS REPORT

PATENT STATUS

This document copy, since it is transmitted in advance of patent clearance, is made available in confidence solely for use in performance of work under contracts with the U. S. Atomic Energy Commission. This document is not to be published nor its contents otherwise disseminated or used for purposes other than specified above before patent approval for such release or use has been secured, upon request, from the Chief, Chicago Patent Group, U. S. Atomic Energy Commission. 9800 So. Cass Ave., Argonne, Illinois.

PRELIMINARY REPORT

This report contains information of a preliminary nature prepared in the course of work under Atomic Energy Commission Contract AT(45-1)-1830. This information is subject to correction or modification upon the collection and evaluation of additional data.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

AEC-RL RICHLAND, WASH.

~~CONFIDENTIAL~~

CONFIDENTIAL

BNWL-934

C-91, Nuclear Reactors
for Rocket Propulsion
(M-3679, 59th Ed.)

QUARTERLY PROGRESS REPORT
FUELED GRAPHITE STUDIES
JULY, AUGUST, SEPTEMBER, 1968

By

Ceramics Department

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

LEGAL NOTICE

This report was prepared as an account of Government-sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of the report for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

January 1969

UNCLASSIFIED

RESTRICTED DATA

This document contains Restricted Data as defined in the Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

SUBMITTED TO AEC DEC 26'68

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON 99352

GROUP 1

Excluded from Automatic Downgrading
and Declassification

CONFIDENTIAL

~~DISTRIBUTION OF THIS DOCUMENT IS LIMITED
To Government Agencies and Their Contractors~~

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

UNCLASSIFIED

ii
BNWL-934

Printed in the USA. Charge \$0.90.
Available from the
U.S. Atomic Energy Commission
Division of Technical Information Extension
P.O. Box 62, Oak Ridge, Tennessee
Please direct to the same address inquiries covering
procurement of other classified AEC reports.

UNCLASSIFIED

~~CONFIDENTIAL~~

iii
BNWL-934

CONTENTS

LIST OF FIGURES	iv
INTRODUCTION	1
EXPERIMENT 50	2
Optical Microscopy - E. M. Woodruff	2
Scanning Electron Microscopy - E. M. Woodruff	6
Radiography - L. R. Bunnell	8
EXAMINATION OF WANL ELEMENTS - L. R. Bunnell	17
Radiography	17
COATING STUDIES	24
Vacuum Impregnation - C. E. McNeilly and H. T. Blair	24
Examination of Coatings - L. R. Bunnell	25
FOREIGN TRAVEL - E. M. Woodruff	32
REFERENCES	35
APPENDIX A: EXPERIMENT 50 ELEMENT DESCRIPTIONS	A-1

~~CONFIDENTIAL~~

FIGURES

1. Typical Examples of Two Modes of Corrosion	4
2. Scanning Electron Micrograph of NbC Roots	7
3. Area A of Figure 2	7
4. Area B of Figure 2	7
5. Area A of Figure 4	7
6. Section View of Fracture Through Bore Coat. Scanning Electron Micrograph of Station 30, Element 3023-AA-254	9
7. Plan View of Bore Surface. Scanning Electron Micrograph of Station 30, Element 3023-AA-254	10
8. Macroradiograph from Station 45 of Element 3110-AA-17 (Unfueled, Wood Flour, Overpressure Tested 60 min)	14
9. Macroradiograph from Station 45 of Element 3110-AA-20 (Unfueled, Wood Flour, Underpressure Tested 54 1/3 min)	15
10. Microradiograph Showing Material (Presumably Molybdenum Overcoat) Peeling Away from Inner Bore Coating Surface at Station 30 in Element 3023-AA-254 (Regular-Mix, Unfueled, Tested 57 1/2 min Underpressure)	16
11. Macroradiograph from Station 47 1/2 of Element AL-20-81344	18
12. Macroradiograph from Station 47 1/2 of Element 431-1042308	19
13. Macroradiograph from Station 18 1/2 of Element AL-20-81344, As Impregnated by Bore-Access Staining	21
14. Microautoradiograph Showing Matrix of Resinate-Containing Element 431-1042309 at Station 19	22

~~CONFIDENTIAL~~

V
BNWL-934

15.	Microautoradiograph Showing Matrix of
Element 431-1042796, Containing No
Resinate-Derived NbC at Station 19	22
16.	Microautoradiograph Showing Matrix of
Element 432-3079889, Containing
-325 Mesh NbC, at Station 19	23
17.	Microradiograph Showing Root Structure
in Element 12a-3	28
18.	Microradiograph Showing Poor Rooting in
Element 13a-3	28
19.	Microradiograph Showing Extremely Good
Rooting in Element 15a-3	29
20.	Microradiograph Showing Good Rooting in
Element 16a-1	29
21.	Micrograph (As-Polished) of Element 13a-2
Showing Roots Pulling Away Large Piece
of Graphite	30
22.	Micrograph (As-Etched) of Element 16a-1
Showing Odd Etching Behavior and Diffuse
Line Separating Coat Layers	30
23.	Microradiograph Showing Small Amount of
Rooting in Vacuum-Impregnated Coating (Run 18a)	31

~~CONFIDENTIAL~~

QUARTERLY PROGRESS REPORT
FUELED GRAPHITE STUDIES
JULY, AUGUST, SEPTEMBER, 1968

INTRODUCTION

A study of the effect of porosity in ROVER fuel and its relationship to hydrogen corrosion is under investigation at Los Alamos Scientific Laboratory (LASL). This study, Experiment 50, involves both fueled and unfueled elements with differences in permeability created through the additions of wood flour. The corrosion during hot-gas tests is compared in the cases where the helium-blanket gas is at a pressure both above and below the hydrogen gas pressure in the fuel bores. Metallographic and radiographic examination of samples from these tests has been performed at Battelle-Northwest, and the concluding phases of this study are reported here. Earlier stages of examination have been reported in preceding progress reports.⁽¹⁻³⁾ Condensed descriptions of the processing and test histories of each element are given in Appendix A.

Other topics covered in this report include studies of the structure of coatings produced in an experimental coating furnace; radiographic studies of hot-tested elements fabricated with NbC particles added to the matrix; scanning electron microscopy of coating structures; and observations relevant to ROVER graphite applications made during visits to several sites in Europe.

EXPERIMENT 50OPTICAL MICROSCOPY - E. M. Woodruff

Optical microscopy has been completed on twenty-five of the twenty-seven Experiment 50 elements. The remaining two elements are currently being processed. The approach for optical microscopy has been to examine transverse sections cut at Station 1, at the peak of midband corrosion, and at Station 40. Other corrosion peaks indicated by MULE incremental weight-loss data were sampled in some elements. Micrographs (250X) were taken to show bore-coat characteristics, adherence, and corrosion in coolant channels 1 and 10.

The appearance of elements before testing was described in an earlier report.⁽¹⁾ In brief, they were characterized by tight coating and extensive root development in all elements at Station 1; separations appeared in the fueled, standard-mix element at Station 15, while the fueled element with a wood-flour addition and both unfueled elements (standard and with wood flour) remained tightly bonded. Coating separations appeared at Station 40 in all elements, with gap widths up to 0.5 mil in fueled elements and 0.2 mil or less in the unfueled elements.

In assessing changes which occurred during testing, it is immediately obvious that optical microscopy does not have the capability for discerning the rather gross differences in the amount of midband corrosion implied by incremental weight-loss (MULE) data. Fortunately, radiography performed on these elements has this capability. Optical microscopy does, however, add to the total picture of corrosion by adding information on the coating-matrix gap widths and suggests the existence of two

types of corrosion pattern, typified in Figures 1a and 1b. These are classed as pits when localized attack creates cavities by removal of both binder and filler material (Figure 1a), and crack enlargement when the attack spreads through the matrix following primarily binder and binder-filler interfaces (Figure 1b). The distinction between the two is better in mid-band regions and in elements tested for short or intermediate periods. Gross corrosion near the exit end of elements takes the form of large pits, which masks any evidence of the manner in which they developed.

Optical observations for Experiment 50 are summarized in Table 1 using measurements of the coating-matrix separation and the depth of the two types of corrosion. Several general conclusions related to element and test variables follow:

1. Previous observations on untested elements indicated wood-flour additions aided rooting and reduced coating-matrix separation. This reduction of gap widths is retained during both underpressure and overpressure tests.
2. Pitting type of corrosion is more prevalent in overpressure tests.
3. Corrosion by crack enlargement is more characteristic of underpressure tests. An example of this type of corrosion extending from the outer-twelve bores to the outer surface of the element was found at Station 20 in the 57 1/2 min underpressure tested, fueled, standard-mix element.
4. Two and three cycle tests of 40 min duration resulted in exit end corrosion equivalent to or greater than that found after one 60 min test.

a.

250X

b.

250X

FIGURE 1. *Typical Examples of Two Modes of Corrosion*

- a. Pitting attack removes both binder and filler and is often associated with cracks through coating.*
- b. Crack enlargement selectively removes binder only and often follows binder-filler interfaces.*

TABLE 1. Experiment 50 - Summary of Gap and Corrosion Observations Made by Optical Microscopy

Element No.	Time, min	Test		Station	Midband			Station	Exit End		
		Pressure	Furnace		Gap Width, mils	Pit Depth, mils	Crack Enlargement Depth, mils		Gap Width, mils	Pit Depth, mils	Crack Enlargement Depth, mils
<u>Unfueled, Standard Mix</u>											
3023-AA-235	0			15	0	0	0	40	0	0	0
								50	0	0	0
3023-AA-252	30	Over	3	12	0	0	2	40	0-0.1	2	1
				32	0.1-0.2	0	1.5				
3023-AA-242	20+12+8	Over	3	12	0	1	0	40	0.2	1-2	0
3023-AA-283	20+20	Over	3	12	0	0	2	40	0.2	5	0
3023-AA-284	60	Over	3	13	0.2	2	4	40	0.2	2	0
3023-AA-196	15	Under	3	12	0	0	4	40	0.2	1	3
				31	0.3	0	4				
3023-AA-281	30	Under	3	21	0.1	0	3	40	0.2	1.5	2
3023-AA-254	57 1/2	Under	3	20	0.2	0	1.5	40	0.2-0.3	2	4
<u>Unfueled + 2% Wood Flour</u>											
3110-AA-2	0			15	0	0	0	40	0.1-0.3	0	0
								50	0.2-0.5	0	0
3110-AA-14	30	Over	5	12	0.1	0	3	40	0.1-0.4	2.5	0
3110-AA-18	30	Over	3	21	0.1	0	2	40	0.1-0.2	2	5
3110-AA-17	60	Over	3	12	0.1	1	4	40	0.2	3-5	0
3110-AA-15	15	Under	3	12	0	0	1	40	0.2	0	3
3110-AA-22	30	Under	3	11	0	0.7	0	40	0.2	2	0
3110-AA-20	54 1/3	Under	3	12	0	0	4-8	40	0.1-1	3-4	0
				19	0.1	0	3				
<u>Fueled, Standard Mix</u>											
210-46213	0			15	0.3	0	0	40	0.7	0	0
								50	1	0	0
210-46214	30	Over	5	15	0.2-0.5	0	5	40	1 1/5	2	0
								50	2	10+	0
210-46216	30	Over	3	15	0.2	0.5	0	40	0.5-1	1	2
210-46218	60	Over	3	16	0.5-1	1	0	40	1	3	0
210-46220	15	Under	3	15	0.2	0	1-2	40	0.8	0	1
210-46215	30	Under	3	12	0.2	0	1	40	0.8	0	1-2
				27	0.8	0	1.5				
210-46219	44 1/2	Under	3	17	0.5	0	1	40	1	3	0
				25	0.5	0	1				
<u>Fueled + 2% Wood Flour</u>											
02-2051-90185	0			15	0	0	0	40	0.5	0	0
								50	0.7	0	0
02-2051-90188	30	Over	3	Not Completed							
02-2051-90184	60	Over	3	1*	0.1-0.2	0	1	40	0.5	0	4
				12	0	1-3	0				
02-2051-90187	15	Under	3	Not Completed							
02-2051-90183	30	Under	3	1*	0.1	0	0	40	0.5	0	3
				13	0.1-0.2	1-2	0				
				20	0.2	0	2				

* Inlet end

CONFIDENTIAL

CONFIDENTIAL

BNWL-934

SCANNING ELECTRON MICROSCOPY - E. M. Woodruff

A scanning electron microscope was installed in June and several bore-coat samples have been examined to explore the capabilities of this instrument in ROVER studies.

Until now, the underside of bore coats has been inaccessible for direct examination, particularly in the case of adherent coats. Delicate NbC root structures penetrating the graphite matrix have been detected in thin sections by radiography; however, for direct examination in the scanning electron microscope a method for exposing roots without damage is required. Specimens have been successfully prepared by selectively removing the graphite in hydrogen at 1500 °C. Half-inch-long sections of an element were cut to include one coolant channel and about half of the surrounding graphite web. Exposure to hydrogen for 10 1/2 hr in an induction furnace removes most of the graphite. Cementing fragments of the coating to copper specimen mounts with silver conductive cement completes the sample preparation for the scanning microscope.

Figures 2 through 5 show an NbC under-surface exposed in this manner at magnifications ranging from 100X to 10,000X. The sample is from Station 4 of LASL Experiment 50 element 3110-AA-2. At low magnifications, a number of relatively large voids appear (Figure 3) in the maze of roots. These were apparently regions occupied by relatively dense filler particles which the root networks did not penetrate.

In Figure 4, a series of roughly parallel striations (lower left) suggest the NbC replicated fractures on the original surface of a graphite particle. It will be

100X

FIGURE 2. Scanning Electron Micrograph of NbC Roots

750X

FIGURE 3. Area A of Figure 2

1000X

FIGURE 4. Area B of Figure 2

10,000X

FIGURE 5. Area A of Figure 4

informative to determine how the original graphite surface irregularities are modified as coating thickness increases, and it appears that the underside of the coating will serve as a replicating medium yielding information about both sides of the NbC-graphite interface.

At 10,000X in Figure 5, individual grains in the 0.3 to 1 μ size range are resolved. Porosity evident here at all levels of magnification may account for closed porosity normally found within thicker NbC coats, if the carbon contained in inclusions formed early in the coating process eventually diffuses toward the deposition surface.

Figure 6 is a section view of a fracture through a bore coat from Station 30 in a tested element (3023-AA-254), which appeared in radiographs to be in the process of losing the molybdenum overcoat. Scanning electron microscopy confirms this and also reveals the departure proceeds through a succession of at least three layers that individually curl and peel away. Figure 7 is a plan view of the bore surface on the same sample. Samples taken upstream and downstream from this position are being prepared for examination.

Another series of samples of the undersurface of the bore coat at intervals along the entire length of an element is being prepared for scanning electron microscopy.

RADIOGRAPHY - L. R. Bunnell

The last three quarterly progress reports⁽¹⁻³⁾ have contained results of radiographic examination of Experiment 50 elements, including untested standards and elements hot-gas tested for the longest time (1 hr, nominal). All of the other hot-gas tested elements in the experiment have now been

2000X

FIGURE 6. *Section View of Fracture Through Bore Coat.
Scanning Electron Micrograph of Station 30,
Element 3023-AA-254*

~~CONFIDENTIAL~~

10
BNWL-934

2000X

FIGURE 7. *Plan View of Bore Surface. Scanning Electron Micrograph of Station 30, Element 3023-AA-254*

~~CONFIDENTIAL~~

examined. The experimental method was the same as used previously,⁽⁴⁾ with samples taken at Stations 1 and 40, and at intermediate stations representing peaks in the MULE weight-loss profile.

The microradiographs of the elements hot-gas tested for shorter times were similar to those tested for 1 hr, except for decreased corrosion. The results, grouped as to element type, are discussed below.

Wood-Flour Addition, Unfueled

No anomalies appeared in the radiographs. Station 1 remained impermeable to stain as observed before. At all other stations, stain access was general as in the untested elements. Penetrations to external surfaces occurred in the Station 20 area in underpressure tests but decreased in extent by Station 40.

Regular-Mix, Unfueled

Corrosion patterns do not correlate with weight losses as well as they did for longer test times, perhaps due to smaller less noticeable defects. In the thermally cycled elements (3023-AA-242 and 3023-AA-283) overpressure tested incrementally for 20 + 12 + 8 and 20 + 20 min, respectively, there was no obvious effect caused by thermal cycling. Very small penetrations to external surfaces occurred in the Station 20 range of underpressure tested elements (a few appeared in overpressure tested elements), but gross weight losses associated with the longer-tested elements did not occur.

Wood-Flour Addition, Fueled

As manufactured, the elements were tight at Stations 1 and 15, and permeable at higher-numbered stations. All of the

hot-gas tests caused 10-20 range stations to be permeable to stain, while Station 1 remained tight. A few penetrations to external surfaces occurred in the Station 10-20 range, mostly on underpressure tested elements. No areas of gross weight loss were visible.

Regular-Mix, Fueled

The untested element was similar to its wood-flour counterpart in being slightly tighter at Station 15 than at 40. All of the hot-gas tested elements had increased stain access in the Station 10 to 20 range. A few small penetrations to external surfaces were visible in the Station 10-20 range of 15- and 30-min underpressure tested elements, but were not responsible for substantial weight losses.

In summary, the corrosion associated with the longer hot-gas test times was more easily detectable by the radiographic method. The short test times showed evidence of incipient corrosion and underpressure tested elements often had penetrations to external surfaces which are apparently enlarged as hot-gas testing proceeds. It is estimated that a fairly localized weight loss of 0.1 g/in. is easily detectable by eye, and the weight loss is about 0.3 g/in. when the corrosion is uniform. (These correspond to mass losses of 0.8 and 2.4 mg, respectively, in the 8-mil sections used in the micro-radiography experiments.)

Further examination of the elements tested for 1 hr has revealed an interesting corrosion pattern. As noted previously,⁽³⁾ an odd annular-ring corrosion habit occurs near Station 40 in underpressure tested unfueled elements, especially those containing wood-flour. To aid in understanding

this phenomenon, samples were cut from Station 45 of the unfueled elements hot-gas tested 1 hr (nominal) in both overpressure and underpressure conditions. Bore-access impregnation and microradiography revealed that the underpressure elements, both regular-mix and with wood-flour, had an increased annular-ring attack over that observed at Station 40. The overpressure tested elements also exhibited this corrosion mode at Station 45, but to a lesser extent.

Figures 8 and 9 depict the behavior described above. These sections were taken from Station 45 of element 3110-AA-17 (unfueled, 2% wood-flour addition, overpressure tested 60 min) and 3110-AA-20 (unfueled, 2% wood-flour addition, underpressure tested 54 1/3 min), respectively. Notice that in the case of the underpressure-tested element (Figure 9) graphite is lost from external surfaces of the element (arrow) as well as around the bore holes. Station 40 samples from the fueled counterparts of these elements did not show a similar behavior.

While attempting to determine by radiography whether the annular-ring attack occurred at lower station numbers, an interesting feature was discovered, as shown in Figure 10. The inner surface of the bore coating was covered with very thin layers of material (on the order of 1 μ thick), apparently the molybdenum overcoat, which was peeling away. This sample was examined by scanning electron microscopy as discussed earlier in this report.

~~CONFIDENTIAL~~

8.5X

FIGURE 8. Macroradiograph from Station 45 of Element 3110-AA-17 (Unfueled, Wood-Flour, Overpressure Tested 60 min). Annular-Ring Attack Occurs to a Much Lesser Extent Than Shown in Figure 9. Weight Loss - 0.32 g/in. in This Region

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

15
BNWL-934

8.5X

FIGURE 9. Macroradiograph from Station 45 of Element 3110-AA-20 (Unfueled, Wood-Flour, Underpressure Tested 54 1/3 min). Arrow Indicates Graphite Loss from External Surface. Weight Loss - 0.69 g/in. in This Region

~~CONFIDENTIAL~~

CONFIDENTIAL

16
BNWL-934

100X

FIGURE 10. *Microradiograph Showing Material
(Presumably Molybdenum Overcoat)
Peeling Away from Inner Bore
Coating Surface (Top) at Station 30
in Element 3023-AA-254 (Regular-Mix,
Unfueled, Tested 57 1/2 min Under-
pressure)*

CONFIDENTIAL

EXAMINATION OF WANL ELEMENTS

L. R. Bunnell

RADIOGRAPHY

Microradiography of the hot-gas-tested counterparts of untested WANL elements described previously⁽³⁾ was completed. Table 2 contains a brief description of the elements involved.

TABLE 2.

<u>Element</u>	<u>Matrix</u>	<u>Impregnation</u>	<u>Test Condition*</u>
431-1042264	Graphite	Nb Resinate	Corrosion Tested 2580 °C at Station 49
AL-20-81344	Graphite	Nb Resinate	Corrosion Tested 2520 °C at Station 49
431-1042308	Graphite	None	Corrosion Tested 2487 °C at Station 49
432-30-79887	Graphite + 2.5% NbC	None	Corrosion Tested 2535 °C at Station 49

* All corrosion testing 3 cycles - 20 min each.

One of the most noticeable features of these tested elements is the variety of fuel-bead migration patterns in samples which were all cut from Station 47 1/2. Figures 11 and 12 illustrate two of these patterns. Hot-gas test temperature profiles were furnished with the samples and show that, although small temperature differences existed at Station 47 1/2, they probably were not large enough to explain the different migration patterns. Different hydrogen flow rates through the bores may be the reason for the differences.

CONFIDENTIAL

18
BNWL-934

8.5X

FIGURE 11. *Macroradiograph from Station 47 1/2 of Element AL-20-81344. A Pie-Shaped Zone of Much Decreased Fuel Migration Extends to the Center of the Element. Gray Images in This Zone Are Due to the Resinate-Deposited NbC in This Element.*

CONFIDENTIAL

8X

FIGURE 12. *Macroradiograph from Station 47 1/2 of Element 431-1042308. In This Element a Cooler Zone Apparently Existed Immediately Around the Center Bore Hole. Element Inadvertently Cut Longitudinally. Examination of Other Half of Element Showed Migration Pattern to be Symmetrical.*

Two of the four elements were inadvertently split lengthwise before they were sent. This made bore-access impregnation of the corroded regions less satisfying than when an entire cross section could be used. A feature was noticed in the sample from Station 18 1/2 of element AL-20-81344 which is rather interesting because it has not been noticed in elements previously examined. Staining of the sample, shown in Figure 13, illustrates corrosion at the No. 10 bore hole, which is a current problem, though center bore corrosion has not been a feature of the LASL Experiment 50 elements examined to date. Notice the annulus of tight graphite (in white) surrounding corrosion of the No. 10 bore hole, and the large number (~9) of broken beads in this area.

In addition to other examinations of untested elements,⁽³⁾ microautoradiography was performed on the elements in the untested condition and after hot-gas testing, to determine whether fuel had migrated to the NbC-graphite interface during coating, and to assess the role of the various NbC additions in the fuel movement. The experimental method used has been described.⁽⁵⁾

All of the as-coated elements had alpha tracks at the NbC-graphite interface; some tracking appeared at Station 19, and much more at Station 47 1/2. In the two elements containing resinate-derived NbC, the matrix graphite contained tracked areas corresponding to porous regions where the resinate-derived NbC was supposedly located (Figure 14). Niobium-carbon particles themselves are either too small to see or are obscured by tracks. The matrix of the element containing no NbC has pores unmarked by tracks (Figure 15). The element containing -325 mesh NbC additions showed little or no tracking surrounding the NbC particles, as shown in Figure 16.

8X

FIGURE 13. *Macroradiograph from Station 18 1/2 of Element AL-20-81344, As Impregnated by Bore-Access Staining. Note Zone of Increased Attack Around No. 10 Bore Hole. Resinate-Impregnated NbC is Responsible for Most of the Stained Regions in the Rest of the Section.*

500X
FIGURE 14. Microautoradiograph Showing Matrix of Resinate-Containing Element 431-1042309 at Station 19. Alpha Tracks Are Clustered, Presumably Around Small NbC Particles.

500X
FIGURE 15. Microautoradiograph Showing Matrix of Element 431-1042796, Containing No Resinate-Derived NbC at Station 19. Tracks Occur at Random, Showing More Uniform Uranium Contamination. "A" Is a Pore.

500X

FIGURE 16. *Microautoradiograph Showing Matrix of Element 432-3079889, Containing -325 Mesh NbC, at Station 19. The Arrow Indicates an NbC Particle; Particles Are Not Surrounded by Tracks, Indicating Little Uranium Pickup.*

In the tested condition, all elements contained about the same track density at Station 18 1/2, with much-increased tracking due to fuel migration at Station 47 1/2. The tracking was so dense at the high-numbered stations that it could not be determined if resinate-derived NbC contained uranium. The -325 mesh NbC contained uranium at the high-numbered stations as a result of hot-gas testing.

COATING STUDIESVACUUM IMPREGNATION - C. E. McNeilly and H. T. Blair

The influence of vacuum impregnation in developing root structure was investigated during the past quarter. The experimental coating furnace was modified to contain a graphite jig for a single element and a mechanical vacuum pump was connected to the furnace exit line. Five coating runs were successfully completed. Before each run, the element was leached with 20% HCl-80% Ar gas for 3 hr at 1800 °C and then for 3 hr at 1600 °C.

The first element was vacuum impregnated at a pressure of 64 μ and was described previously.⁽³⁾ The second element (Run 18a) was vacuum impregnated at a pressure of 35 μ with the furnace at about 600 °C. After bringing the system to 1 atm in helium, hydrogen and HCl were introduced according to the fast coating conditions described above. The furnace was then heated to 1600 °C over a time period of 15 min and shut off. The element gained 1 g. The third element (Run 19a) was vacuum impregnated at 40 μ with the furnace temperature at about 600 °C, using the same procedure described for Run 18a, with the exception that the furnace was heated to only 1400 °C and the gas flow continued at this temperature for 45 min. This element gained 3.7 g and the coating extended farther down the bore of the element. The fourth coating (Run 20a) began as an attempt to vacuum impregnate the element at room temperature to promote greater condensation of the NbCl₅ vapor. This resulted in plugging at the top of the furnace. After the plug was removed, the entire furnace was evacuated to about 40 μ and heated to 1200 °C. The system was brought to 1 atm and hydrogen and HCl introduced under the slow coating

conditions. Coating was carried out under these conditions for 4 hr and a heavy coating resulted in the bores. The final element (Run 21a) was vacuum impregnated with the entire furnace at 43 μ and 600 °C. After introducing helium through the saturator, the element was heated to 1400 °C under slow coating conditions. Coating was continued for 4 hr and the element gained 4.9 g.

Coatings made in the temperature range 1200 to 1400 °C have been examined by radiography as described below. Though extensive root formation was not observed during the initial vacuum coating runs, additional experimental variables need to be investigated to thoroughly assess this technique.

EXAMINATION OF COATINGS - L. R. Bunnell

Examination of coatings produced in the PNL experimental coater was done using microscopy, microradiography, and microautoradiography. The main series of samples examined was the result of draw trial experiments where the elements were coated rapidly with removal of elements from the furnace at time periods up to 4 hr maximum and slowly, with removal up to 30 hr maximum. The gas composition during the fast and slow coating conditions are given in Table 3.

TABLE 3. *Experimental Coating Conditions*

<u>Gas Composition</u>	<u>Run No.</u>	<u>Time in Coater</u>	<u>Weight Gain, g</u>
<u>Fast</u>			
NbCl ₅ - 0.006 moles/min	12a - 3	10 min	0.8
3% of total flow	12a - 1	20 min	1.6
H ₂ /NbCl ₅ - 2.2	12a - 2	30 min	1.9
HCl/NbCl ₅ - 1.0	13a - 3	60 min	8.0
He - remainder	13a - 1	120 min	2.0
	13a - 2	240 min	25.0
<u>Slow</u>			
NbCl ₅ - 0.001 moles/min	15a - 1	1 hr	0.8
1% of total flow	15a - 2	2 hr	1.3
H ₂ /NbCl ₅ - 2.0	15a - 3	4 hr	1.1
HCl/NbCl ₅ - 1.0	16a - 1	8 hr	4.3
He - remainder	16a - 3	16 hr	13.2
	16a - 2	30 hr	16.3

The results of all the observations on these coatings are given in Table 4, with reference to photomicrographs where necessary.

The vacuum impregnated coatings described above were examined using microradiography, because of its applicability in root characterization. None of the vacuum-impregnation experiments performed to date produced a root network as extensive as that produced during slow coating. Figure 23 is an example of the rather limited rooting at Station 5 from Run 18a. This rooting is fairly typical of that noted on all of the vacuum-impregnation coating experiments.

TABLE 4. Examination of Experimental Coatings

Sample No.	Coating Conditioner	Coat Thickness at Station 5, mils	Weight Gain, g	Coating	Comments
12a-3	10 min-fast	0	0.8	Fair (Figure 17)	Very thin "frosting"
12a-1	20 min-fast	0.25	1.6	Fair (similar to Figure 17)	Very tight
12a-2	30 min-fast	0.3	1.9	Fair	Very tight
13a-3	1 hr-fast	0.3	8.0	Poor - only penetration into fuel bead sockets (similar to Figure 18)	Very tight
13a-1	2 hr-fast	0.9	2.0	Fair	Very tight appearing interface
13a-2	4 hr-fast	3.3	25.0	Poor	Adherent in placed, pulling away in others (Figure 21), large grains at inner surface. Microautoradiography showed no tracking at interface.
15a-1	1 hr-slow	0	0.8	Good*	Very fine grained, tight
15a-2	2 hr-slow	0.1	1.3	Good	Tight, very thin
15a-3	4 hr-slow	0	1.1	Extremely good (Figure 19)	No coat showed in micro-graph
16a-1	8 hr-slow	1.3	4.3	Good (Figure 20)	Odd etching behavior near fuel bead. Fine-grained initial layer, with large columnar grains on top, separated by diffuse interface. (Figure 22)
16a-3	16 hr-slow	3.5	13.2	Good	Similar to Figure 22, even larger columnar grains. Tight coat
16a-2	30 hr-slow	4	16.3	Good	No α -tracking at NBC-graphite interface. Adherent coat

* "Good" refers to a generally tight coating, relatively free of radial cracks or cracking in the graphite below.

CONFIDENTIAL

CONFIDENTIAL

~~CONFIDENTIAL~~

28
BNWL-934

40X

FIGURE 17. *Microradiograph Showing Root Structure
in Element 12a-3*

40X

FIGURE 18. *Microradiograph Showing Poor Rooting
in Element 13a-3*

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

29
BNWL-934

40X

FIGURE 19. *Microradiograph Showing Extremely Good Rooting
in Element 15a-3*

40X

FIGURE 20. *Microradiograph Showing Good Rooting
in Element 16a-1*

~~CONFIDENTIAL~~

250X

FIGURE 21. Micrograph (As-Polished) of Element 13a-2, Showing Roots Pulling Away Large Piece of Graphite. A Stoichiometry Shift to NbC-Rich Structure Occurred in the Location Indicated by the Arrow

250X

FIGURE 22. Micrograph (As-Etched) of Element 16a-1, Showing Odd Etching Behavior and Diffuse Line Separating Coat Layers

~~CONFIDENTIAL~~31
BNWL-934

40X

FIGURE 23. *Microradiograph Showing Small Amount of Rooting in Vacuum-Impregnated Coating (Run 18a). The Sample Was Impregnated, Then Heated to 1600 °C and Held at Temperature for 30 min with "Fast" Coating Gas Flows.*

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

32
BNWL-934

FOREIGN TRAVEL

E. M. Woodruff

Observations relevant to ROVER graphite applications made during a trip to Europe in June and July are listed below. The trip included the carbon and graphite conferences at Paris and Newcastle and visits to the Dragon Project, Winfrith, England, the AVR-THTR Project, Jülich, Germany, and the Nukem plant near Hanau, Germany, where fuel is fabricated for the AVR-THTR pebble-bed reactors.

1. The theme for the Paris conference was "Fundamental Aspects of Carbonization and Graphitization." Throughout the conference, many references were made to the catalysis of graphitization by foreign elements. Several papers dealt specifically with the effects of K, CaCO_3 and $\text{CaMg}(\text{CO}_3)_2$, Fe and Cr. Research in this area appears to be increasing and is worth examining as a means of increasing the state of graphitization of the binder in ROVER fuel without increasing process temperatures. The objective would be to reduce the susceptibility of binder to corrosion. A reprint⁽⁶⁾ obtained from J. Gillot, Battelle-Geneva, is particularly relevant because it describes the effects of titanium and vanadium on nongraphitizing furfuryl alcohol coke. Complete conversion of the coke to a graphite state took 20 hr at 2600 °C for titanium and 20 hr at 2200 °C for vanadium, using 5 wt% additions.
2. E. H. Boulton, who operates the microscopy laboratory for the School of Chemistry, University of Newcastle, has found the resolution of scanning electron

~~CONFIDENTIAL~~

microscopy is greatly enhanced by metallizing the surfaces even on metallic samples which are themselves conductors. He had devised a system⁽⁷⁾ for metallizing up to eight samples with the angle of evaporation varied from 30 to 90 degrees. Carbon chars metallized with gold or 40% gold-palladium wire gave excellent resolution for a study of porosity changes during oxidation.

3. Fuel elements for the pebble-bed AVR and THTR reactors are made by Nukem at a plant near Hanau, Germany, using a dry-mix, semihydrostatic, pressing operation. The spherical elements have an unfueled graphite core, a layer containing PyC-coated UO_2 beads in a graphite matrix, and an unfueled outer shell. The fabrication method of machining a hollow graphite sphere, inserting fuel, and plugging has been replaced by cold pressing dry-micronized ingredients which, for the matrix, consist of 20% artificial graphite powder, 70% natural graphite powder and powdered phenol formaldehyde binder. Pressing is done in silicone-rubber molds having elliptical cavities which become spherical in a double ram press. The key to baking these cold-pressed bodies to 1800 °C without excessive deformation and cracking is the artificial graphite constituent, which provides porosity for the release of gases evolved during decomposition of the binder. By adjusting the artificial graphite content in the mix, swelling, shrinkage, or no dimensional change can be attained.

The fuel beads are prewrapped in a graphite-binder mix in a "candy coating" process developed for the Dragon Project. This outer shell of matrix aids dispersion of beads and prevents damage during pressing.

Dry fabrication has obvious advantages in processing fuels of complex geometry which could alleviate difficulties inherent in current ROVER elements. The ability to form fueled and unfueled zones in an element offers a means of preparing unfueled zones near bores to eliminate bead damage during reaming and the subsequent need for leaching. Matrix-wrapped beads could be incorporated in the present ROVER fabrication to reduce bead damage during mixing and extrusion.

REFERENCES

1. Quarterly Progress Report, Fueled-Graphite Studies, October, November, December, 1967, BNWL-731. Pacific Northwest Laboratory, Richland, Washington, May 1968. (Confidential)
2. Quarterly Progress Report, Fueled-Graphite Studies, January, February, March, 1968, BNWL-798. Pacific Northwest Laboratory, Richland, Washington, June 1968. (Confidential)
3. Quarterly Progress Report, Fueled-Graphite Studies, April, May, June, 1968, BNWL-853. Pacific Northwest Laboratory, Richland, Washington, August 1968. (Confidential)
4. L. R. Bunnell. Microradiography of Porosity in ROVER Fuel Elements, BNWL-596. Pacific Northwest Laboratory, Richland, Washington, January 1968. (Confidential)
5. L. R. Bunnell. Microautoradiographic Characterization of ROVER Bore Coating Interfaces, BNWL-737. Pacific Northwest Laboratory, Richland, Washington, August 1968. (Confidential)
6. J. Gillot, B. Lux, P. Coruault, and F. du Chaffant. "Katalyse der Graphitierung eines Furfurylalkoholkokeses durch Titan and Vanadium," Bericht der Deutschen Keramischen Gesellschaft, Band 45 (1968), Heft 5, Seite 224-230.
7. E. H. Boulton and E. J. Brabazon. "A Rotating Device for Use in Metallizing Nonconducting Scanning Electron Microscope Specimens," Journal of Scientific Instruments, 1968 Series 2, Vol. 1, pp. 565-566.

~~CONFIDENTIAL~~

BNWL-934

APPENDIX A

EXPERIMENT 50 ELEMENT DESCRIPTIONS

~~CONFIDENTIAL~~

APPENDIX A

EXPERIMENT 50 ELEMENT DESCRIPTIONS

<u>Element Type and Number</u>	<u>Test Time, min</u>	<u>Test Condition</u>	<u>Page</u>
<u>Unfueled, Standard Mix</u>			
3023-AA-235	0		A-2
3023-AA-252	30	Overpressure	A-3
3023-AA-242	20+12+8	Overpressure	A-4
3023-AA-283	20+20	Overpressure	A-5
3023-AA-284	60	Overpressure	A-6
3023-AA-196	15	Underpressure	A-7
3023-AA-281	30	Underpressure	A-8
3023-AA-254	57 1/2	Underpressure	A-9
<u>Unfueled + 2% Wood Flour</u>			
3110-AA-2	0		A-10
3110-AA-14	30	Overpressure	A-11
3110-AA-18	30	Overpressure	A-12
3110-AA-17	60	Overpressure	A-13
3110-AA-15	15	Underpressure	A-14
3110-AA-22	30	Underpressure	A-15
3110-AA-20	54 1/3	Underpressure	A-16
<u>Fueled, Standard Mix</u>			
210-46213	0		A-17
210-46214	30	Overpressure	A-18
210-46216	30	Overpressure	A-19
210-46218	60	Overpressure	A-20
210-46220	15	Underpressure	A-21
210-46215	30	Underpressure	A-22
210-46219	44 1/2	Underpressure	A-23
<u>Fueled + 2% Wood Flour</u>			
02-2051-90185	0		A-24
02-2051-90188	30	Overpressure	A-25
02-2051-90184	60	Overpressure	A-26
02-2051-90187	15	Underpressure	A-27
02-2051-90183	30	Underpressure	A-28

~~CONFIDENTIAL~~

A-2
BNWL-934

ELEMENT 3023-AA-235

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110" dia. bores (machined), 0.752-0.754" flat to flat, 54" length.

FORMULATION: Unloaded, standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: Not leached.

COAT BATCH: B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight, 79.95 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element.
Run time, B-3-136: 14 hrs.; B-4-162: 4 hrs.

OVERCOAT: Not overcoated.

PERMEABILITY: Whole body before coating, 10 psig air: 30 cc/min. (lot average 51 cc/min)

ELECTRICAL TEST: Not tested.

FIGURE 1
Coating Temperature

~~CONFIDENTIAL~~

ELEMENT 3023 AA 252

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754 flat to flat .54 length

FORMULATION Unloaded standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162 both G-end diffusion
Total coat weight 78.69 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 g/min/element B-4-162 2.85 g/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321 Total Mo weight 3.30 g
Molybdenum coat thickness MULE est. (g/5 increment) Fig 2

PERMEABILITY Whole body before coating 10 psig air 35 cc/min (lot average 51 cc/min) incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 30 min Overpressure <1-1/2 psi at inlet
no orifices 200 lbs H₂/hr exit gas temp 4500°R (2230°C)
Power 910 kW
Voltage 205 volts
Impedance 67.5 to 74.5 mΩ
Weight Loss 5.3 g Total
0.0 g Exterior
5.3 g Bore
6.09 g MULE est.
MULE incremental Fig 3
Appearance Good
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

ELEMENT 3023-AA-242

SOURCE	LASL (Experiment 50)
TYPE	19 hole hexagonal, 0.110" dia. bores (machined), 0.752 - 0.754" flat to flat, 54" length
FORMULATION	Unloaded, standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C)
LEACH BATCH	Not leached.
COAT BATCH	B-3-136, recoat B-4-162, both G-end diffusion Total coat weight 80.28 g Coating temperature, Fig. 1; coating thickness, Fig. 2 Flow, B-3-136 2.9 l/min/element; B-4-162: 2.85 l/min/element Run time: B-3-136: 14 hrs.; B-4-162: 4 hrs.
OVERCOAT	Molybdenum coat batch: M-3A321, Total Mo weight: 3.30 g Molybdenum coat thickness, MULE est. (g/5" increment) Fig. 2
PERMEABILITY	Whole body before coating, 10 psig air: 70 cc/min. (lot average 51 cc/min), incremental permeabilities Fig. 3.
ELECTRICAL TEST	Phoebus 18 RPT, 20+12+8 (40) min., Overpressure, <1-1/2 psi at inlet, no orifices, 200 lbs H ₂ /hr, exit gas temp. 4500°R (2230°C) Power: 835 kW Voltage: 192 volts Impedance: 69.0 to 75.0 mΩ Weight Loss: 5.6 g Total 0.0 g Exterior 5.6 g Bore 4.38 g MULE est. MULE incremental, Fig. 3. Appearance: Flaked, corroded Pinholes: None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

A-5
BNWL-934

ELEMENT 3023 AA 283

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754
flat to flat .54 length

FORMULATION Unloaded standard ROVER mix Graphitized 4 hours at
4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162 both G-end diffusion
Total coat weight 79.86 g
Coating temperature Fig. 1 coating thickness Fig. 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321 Total Mo weight 3.32 g
Molybdenum coat thickness MULE est (g/5 increment) Fig. 2

PERMEABILITY Whole body before coating 10 psig air 40 cc/min (hot average
was 51 cc/min) incremental permeabilities Fig. 3

ELECTRICAL TEST Phoebus 1B RPT 20+20 (40) min Overpressure <1-1/2 psi
at inlet No orifices, 200 lbs H₂/hr, exit gas temp 4500°R
(2230°C)

Power 945 kW
Voltage 203 volts
Impedance 68.0 to 78.5 mΩ
Weight Loss 14.4 g Total
4.0 g Exterior
10.4 g Bore
9.93 g MULE est
MULE incremental Fig. 3
Appearance Hot end faces sides corroded
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

ELEMENT 3023-AA-284

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110" dia bores (machined), 0.752 - 0.754 flat to flat, 54" length

FORMULATION Unloaded, standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136, recoat B-4-162, both G-end diffusion
Total coat weight 78.90 g
Coating temperature, Fig 1 coating thickness, Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321, Total Mo weight 3.34 g
Molybdenum coat thickness MULE est. (g/5" increment) Fig 2

PERMEABILITY Whole body before coating, 10 psig air 40 cc/min (lot average 51 cc/min) incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 60 min, Overpressure, <1-1/2 psi at inlet
No orifices 200 lbs H₂/hr, exit gas temp 4500°R (2230°C)
Power 850 kW
Voltage 197 volts
Impedance 65.5 to 75.5 mΩ
Weight Loss 7.3 g Total
0.0 g Exterior
7.3 g Bore
7.08 g MULE est.
MULE incremental Fig 3
Appearance Good
Pinholes None

FIGURE 1
Coating Temperature FIGURE 2
Coat Thickness FIGURE 3
Incremental Permeability
and Weight Loss

ELEMENT 3023-AA-196

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110" dia bores (machined), 0.752-0.754 flat to flat, 54" length

FORMULATION Unloaded, standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136, recoat B-4-162, both G-end diffusion
Total coat weight 80.30 g
Coating temperature Fig 1 coating thickness, Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321 Total Mo weight 3.35 g
Molybdenum coat thickness MULE est (g/5" increment) Fig 2

PERMEABILITY Whole body before coating, 10 psig air 110 cc/min (lot average 51 cc/min) incremental permeabilities Fig 3

ELECTRICAL TEST Underpressure, 15 min Helium pressure 30 psi below hydrogen bore pressure at station 20 200 lbs H₂/hr, No orifices exit gas temp 4500°R (2230°C)

Power 920 kW
Voltage 204 volts
Impedance 67.0 to 74.5 mΩ
Weight Loss 6.2 g Total
0.0 g Exterior
6.2 g Bore

MULE incremental Fig 3
Appearance Good
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

A-8
BNWL-934

ELEMENT 3023 AA 281

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752-0.754 flat to flat .54 length

FORMULATION Unloaded standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162, both G-end diffusion
Total coat weight 80.70 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321, Total Mo weight 3.32 g
Molybdenum coat thickness, MULE est (g/5' increment) Fig 2

PERMEABILITY Whole body before coating, 10 psig air 30 cc/min (lot average 51 cc/min), incremental permeabilities Fig 3

ELECTRICAL TEST Underpressure 30 min, Helium pressure 30 psi below hydrogen bore pressure at station 20 200 lbs H₂/hr, no orifices exit gas temp 4500°R (2230°C)

Power 860 kW
Voltage 197.5 volts
Impedance 67.0 to 77.0 mΩ
Weight Loss 10.9 g Total
0.0 g Exterior
10.9 g Bore
8.73 g MULE est
MULE incremental Fig 3
Appearance Cracks at 51-1/8" on A, B, E, F Flats
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-9
BNWL-934

ELEMENT 3023-AA-254

SOURCE	LASL (Experiment 50)												
TYPE	19 hole hexagonal 0.110 dia bores (machined) 0.752-0.754 flat to flat .54 length												
FORMULATION	Unloaded, standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)												
LEACH BATCH	Not leached												
COAT BATCH	B-3-136 recoat B-4-162, both G-end diffusion Total coat weight 80.50 g Coating temperature Fig 1 Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element Run time B-3-136 14 hrs B-4-162 4 hrs												
OVERCOAT	Molybdenum coat batch M-3A321 Total Mo weight 3.38 g Molybdenum coat thickness MULE est (g/5 increment) Fig 2												
PERMEABILITY	Whole body before coating 10 psig air 30 cc/min (lot average 51 cc/min) incremental permeabilities Fig 3												
ELECTRICAL TEST	Underpressure 57-1/2 min, Helium pressure 30 psi below hydrogen bore pressure at station 20 200 lbs H ₂ /hr no orifices exit gas temp 4500°R (2230°C) <table><tbody><tr><td>Power</td><td>925 kW</td></tr><tr><td>Voltage</td><td>204 volts</td></tr><tr><td>Impedance</td><td>66.0 to 75.5 mΩ</td></tr><tr><td>Weight Loss</td><td>16.1 g Total 0.0 g Exterior 16.1 g Bore 12.72 MULE est MULE incremental Fig 3</td></tr><tr><td>Appearance</td><td>Bores corroded from station 44 to H end</td></tr><tr><td>Pinholes</td><td>None</td></tr></tbody></table>	Power	925 kW	Voltage	204 volts	Impedance	66.0 to 75.5 mΩ	Weight Loss	16.1 g Total 0.0 g Exterior 16.1 g Bore 12.72 MULE est MULE incremental Fig 3	Appearance	Bores corroded from station 44 to H end	Pinholes	None
Power	925 kW												
Voltage	204 volts												
Impedance	66.0 to 75.5 mΩ												
Weight Loss	16.1 g Total 0.0 g Exterior 16.1 g Bore 12.72 MULE est MULE incremental Fig 3												
Appearance	Bores corroded from station 44 to H end												
Pinholes	None												

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-10
BNWL-934

ELEMENT 3110-AA-2

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110 dia. bores (machined), 0.752 - 0.754 ' flat to flat, 54" length.

FORMULATION: Unloaded, 2 wt. % wood flour added to standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: Not leached.

COAT BATCH: B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight: 78.43 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element.
Run time, B-3-136: 14 hrs.; B-4-162: 4 hrs.

OVERCOAT: Not overcoated.

PERMEABILITY: Whole body before coating, 10 psig air: <1000 cc/min.
(lot average 730 cc/min)

ELECTRICAL TEST: Not tested.

FIGURE 1
Coating Temperature

FIGURE 2
Coat Thickness

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-11
BNWL-934

ELEMENT 3110-AA-14

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 - 0.754
flat to flat 54 length

FORMULATION Unloaded, 2 wt % wood flour added to standard ROVER mix
Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162, both G-end diffusion
Total coat weight 78.18 g
Coating temperature Fig 1 coating thickness, Fig 2
Flow, B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321 Total Mo weight 3.32 g
Molybdenum coat thickness MULE est. (g/5 increment) Fig 2

PERMEABILITY Whole body before coating 10 psig air 820 cc/min (lot average
was 730 cc/min) incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 30 min, Overpressure <1-1/2 psi at inlet
No orifices 200 lbs H₂/hr, exit gas temp 4500°R (2230°C)
Power 993 kW
Voltage 205.5 volts
Impedance 43.5 to 45.6 mΩ
Weight Loss 9.4 g Total
0.0 g Exterior
9.4 g Bore
9.42 g MULE est
MULE incremental, Fig 3
Appearance Cracks Transverse,
Longitudinal and Diagonal
Pinholes 8 from 51' to 51-7/8"

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-12
BNWL-934

ELEMENT 3110-AA-18

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110" dia. bores (machined), 0.752 - 0.754" flat to flat, 54" length.

FORMULATION Unloaded, 2 wt. % wood flour added to standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH Not leached.

COAT BATCH B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight: 77.95 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element
Run time, B-3-136: 14 hrs., B-4-162: 4 hrs.

OVERCOAT: Molybdenum coat batch: M-2A350, Total Mo weight: 2.97 g
Molybdenum coat thickness, MULE est. (g/5" increment) Fig. 2.

PERMEABILITY Whole body before coating, 10 psig air: 680 cc/min. (lot average 730 cc/min), incremental permeabilities Fig. 3

ELECTRICAL TEST Phoebus 1B RPT, 30 min., Overpressure, <1-1/2 psi at inlet
No orifices, 200 lbs H₂/hr, exit gas temp. 4500°R (2230°C).
Power: 920 kW
Voltage: 208 volts
Impedance: 72.0 to 78.0 mΩ
Weight Loss: 6.2 g Total
0.0 g Exterior
6.2 g Bore
5.89 g MULE est.
MULE incremental, Fig. 3
Appearance: Good
Pinholes: None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

ELEMENT 3110-AA-17

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110 dia bores (machined) 0.752 0.754 flat to flat, 54" length

FORMULATION Unloaded 2 wt % wood flour added to standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162 both G-end diffusion
Total coat weight 77.95 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A350 Total Mo weight 2.92 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body before coating 10 psig air 460 cc/min (lot average 730 cc/min) Incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 60 min Overpressure 1-1/2 psi at inlet
No orifices 200 lbs H₂/hr exit gas temp 4500°R (2230°C)
Power 860 kW
Voltage 201 volts
Impedance 72.5 to 80.0 mΩ
Weight Loss 8.0 g Total
0.0 g Exterior
8.0 g Bore
7.69 g MULE est
MULE incremental Fig 3
Appearance Good
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

A-14
BNWL-934

ELEMENT 3110-AA-15

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110" dia bores (machined), 0.752 - 0.754" flat to flat, 54" length

FORMULATION Unloaded, 2 wt. % wood flour added to standard ROVER mix
Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH Not leached

COAT BATCH B-3-136 recoat B-4-162 both G-end diffusion
Total coat weight 77.73 g
Coating temperature Fig 1 coating thickness, Fig. 2
Flow B-3-136 2.9 L/min/element B-4-162 2.85 L/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-3A321 Total Mo weight 3.30 g
Molybdenum coat thickness MULE est. (g/5" increment) Fig. 2

PERMEABILITY Whole body before coating 10 psig air 660 cc/min (lot average 730 cc/min) incremental permeabilities Fig. 3

ELECTRICAL TEST Underpressure 15 min Helium pressure 30 psi below hydrogen
bore pressure at station 20 200 lbs H₂/hr no orifices exit gas temp 4500°R (2230°C)

Power 940 kW
Voltage 212 volts
Impedance 71.0 to 81.0 mΩ
Weight Loss 6.3 g Total
0.0 g Exterior
6.3 g Bore
6.26 g MULE est
MULE incremental Fig. 3
Appearance No. 19 bore blistered at station 32
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-15
BNWL-934

ELEMENT 3110-AA-22

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110" dia. bores (machined), 0.752 - 0.754" flat to flat, 54" length.

FORMULATION: Unloaded, 2 wt. % wood flour added to standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: Not leached.

COAT BATCH: B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight: 78.44 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element
Run time, B-3-136: 14 hrs.; B-4-162: 4 hrs.

OVERCOAT: Molybdenum coat batch: M-3A321; Total Mo weight: 3.36 g
Molybdenum coat thickness, MULE est. (g/5" increment) Fig. 2.

PERMEABILITY: Whole body before coating, 10 psig air: 630 cc/min. (lot average 730 cc/min), incremental permeabilities Fig. 3.

ELECTRICAL TEST: Underpressure, 30 min., Helium pressure 30 psi below hydrogen bore pressure at station 20. 200 lbs H₂/hr, no orifices, exit gas temp. 4500°R (2230°C).

Power: 880 kW
Voltage: 207 volts
Impedance: 73.0 to 82.0 mΩ
Weight Loss: 9.2 g Total
0.0 g Exterior
9.2 g Bore
5.52 g MULE est.
MULE incremental, Fig. 3.
Appearance: Punky from 19-1/4" to 29-1/2"
Pinholes: None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-16
BNWL-934

ELEMENT 3110-AA-20

SOURCE	LASL (Experiment 50)
TYPE	19 hole hexagonal, 0.110 dia bores (machined), 0.752 - 0.754 flat to flat .54 length
FORMULATION	Unloaded, 2 wt % wood flour added to standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)
LEACH BATCH	Not leached
COAT BATCH	B-3-136 recoat B-4-162, both G-end diffusion Total coat weight 78.51 g Coating temperature Fig 1 coating thickness, Fig 2 Flow, B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element Run time B-3-136 14 hrs B-4-162 4 hrs
OVERCOAT	Molybdenum coat batch M-2A350 Total Mo weight 3.04 g Molybdenum coat thickness MULE est. (g/5 increment) Fig 2
PERMEABILITY	Whole body before coating 10 psig air 990 cc/min (lot average 730 cc/min) incremental permeabilities Fig 3
ELECTRICAL TEST	Underpressure .54 minute 20 second Helium pressure 30 psi below hydrogen bore pressure at station 20 200 lbs H ₂ /hr no orifices exit gas temp 4500°R (2250°C) Power 920 kW Voltage 210 volts Impedance 72.0 to 82.0 mΩ Weight Loss 15.7 g Total 0.0 g Exterior 15.7 g Bore 7.62 g MULE est MULE incremental Fig 3 Appearance Blisters in bores .39 to .50-1/2 Pinholes Hot end 'A' face .50-1/4 to 48-1/4' Size 1/16

FIGURE 1
Coating Temperature

FIGURE 2
Coat Thickness

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-17
BNWL-934

ELEMENT 210-46213

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110 dia. bores (machined), 0.752 - 0.754 flat to flat, 54" length.

FORMULATION: Loaded (213 mg/cc), standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: B-2-22, Uranium Loss: 4.59 g

COAT BATCH: B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight: 76.44 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element.
Run time, B-3-136: 14 hrs.; B-4-162: 4 hrs.

OVERCOAT: Not overcoated.

PERMEABILITY: Whole body before coat, 10 psig air: 90 cc/min.
(lot average 96 cc/min).

ELECTRICAL TEST: Not tested.

FIGURE 1
Coating Temperature

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-18
BNWL-934

ELEMENT 210 46214

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754
flat to flat .54 length

FORMULATION Loaded (213 mg/cc) standard ROVER mix Graphitized 4 hours
at 4540°R (2250°C)

LEACH BATCH B 2 22 Uranium loss 4.60 g

COAT BATCH B 3 136 recoat B 4 162 both G-end diffusion
Total coat weight 79.53 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B 3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B 3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A351 Total Mo weight 3.96 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach 10 psig air 80 cc/min. incremental
permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 30 min Overpressure <1-1/2 psi at inlet
no orifices 200 lbs H₂/hr exit gas temp 4500°R (2230°C)
Power 990 kW
Voltage 209 volts
Impedance 44.1 to 45.1 mΩ
Weight Loss 7.4 g Total
0.0 g Exterior
7.4 g Bore
6.22 g MULE est
MULE incremental Fig 3
Appearance Very good
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 2
Coat Thickness

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-19
BNWL-934

ELEMENT 210 46216

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754
flat to flat .54 length

FORMULATION Loaded (213 mg/cc) standard ROVER mix Graphitized 4 hours
at 4540°R (2250°C)

LEACH BATCH B 2-22 Uranium loss 4.44 g

COAT BATCH B-3-136 recoat B-4-162 both G-end diffusion
Total coat weight 75.13 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A351 Total Mo weight 3.88 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach 10 psig air 105 cc/min
(lot average 96 cc/min) Incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 30 min Overpressure <1-1/2 psi at inlet
no orifices 200 lbs H₂/hr, exit gas temp 4500°R (2230°C)
Power 850 kW
Voltage 205 volts
Impedance 80 Ω to 84.0 mΩ
Weight Loss 5.0 g Total
0.0 g Exterior
5.0 g Bore
4.28 g MULE est
MULE incremental Fig 3
Appearance Cracks on A B E F Flats
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-20
BNWL-934

ELEMENT 210-46218

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110 dia. bores (machined), 0.752 - 0.754 flat to flat, 54" length.

FORMULATION: Loaded (213 mg/cc), standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: B-2-22, Uranium Loss: 4.36 g

COAT BATCH: B-3-136, re-coat B-4-162, both G-end diffusion
Total coat weight: 75.42 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element
Run time; B-3-136: 14 hrs.; B-4-162: 4 hrs

OVERCOAT: Molybdenum coat batch: M-2A351; Total Mo weight: 3.89 g
Molybdenum coat thickness, MULE est. (g/5" increment) Fig. 2.

PERMEABILITY: Whole body after leach, 10 psig air: 155 cc/min. (lot average 105 cc/min) incremental permeabilities Fig. 3.

ELECTRICAL TEST: Phoebus 1B RPT, 60 min., Overpressure, <1-1/2 psi at inlet, no orifices, 200 lbs H₂/hr, exit gas temp. 4500°R (2230°C).

Power: 850 kW
Voltage: 205 volts
Impedance: 80.1 to 83.0 mΩ
Weight Loss: 9.0 g Total
1.5 g Exterior
7.5 g Bore
8.50 MULE est.
MULE incremental, Fig. 3.
Appearance: Cracks at 50-3/4" end of grips.
Pinholes: None

FIGURE 1
Coating Temperature

FIGURE 2
Coat Thickness

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

ELEMENT 210-46220

SOURCE	LASL (Experiment 50)
TYPE	19 hole hexagonal 0.110 dia bores (machined) 0.752 - 0.754 flat to flat, 54 length
FORMULATION	Loaded (213 mg/cc) standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)
LEACH BATCH	B-2-22 Uranium Loss 438 g
COAT BATCH	B-3-136 recoat B-4-162 both G-end diffusion Total coat weight 76.49 g Coating temperature Fig. 1 coating thickness Fig. 2 Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element Run time B-3-136 14 hrs B-4-162 4 hrs
OVERCOAT	Molybdenum coat batch M-2A351 Total Mo weight 3.96 g Molybdenum coat thickness MULE est (g/5 increment) Fig. 2
PERMEABILITY	Whole body after leach 10 psig air 100 cc/min (lot average 96 cc/min) incremental permeabilities Fig. 3
ELECTRICAL TEST	Underpressure 15 min Helium pressure 30 psi below hydrogen bore pressure at station 20 200 lbs H ₂ /hr no orifices exit gas temp 4500°R (2230°C)

Power	890 kW
Voltage	210 volts
Impedance	80.0 795 mΩ
Weight Loss	4.2 g Total 0.0 g Exterior 4.2 g Bore 2.11 g MULE est MULE incremental Fig. 3
Appearance	Flats and bores corroded H end
Pinholes	None

FIGURE 1
Coating Temperature

FIGURE 2

FIGURE 3
Incremental Permeability and Weight Loss

~~CONFIDENTIAL~~

A-22
BNWL-934

ELEMENT 210-46215

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110" dia. bores (machined), 0.752 - 0.754' flat to flat, 54" length.

FORMULATION Loaded, (213 mg/cc), standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH B-2-22, Uranium Loss: 4.49 g

COAT BATCH B-3-136, recoat B-4-162, both G-end diffusion
Total coat weight: 75.48 g
Coating temperature, Fig. 1, coating thickness, Fig. 2
Flow, B-3-136: 2.9 g/min/element; B-4-162: 2.85 g/min/element.
Run time, B-3-136: 14 hrs; B-4-162: 4 hrs.

OVERCOAT Molybdenum coat batch M-2A351, Total Mo Weight: 3.94 g
Molybdenum coat thickness, MULE est. (g/5" increment) Fig. 2

PERMEABILITY Whole body after leach, 10 psig air 60 cc/min (lot average 96 cc/min), incremental permeabilities Fig. 3

ELECTRICAL TEST Underpressure, 30 min, Helium pressure 30 psi below hydrogen bore pressure at station 20. 200 lbs H₂/hr, no orifices, Exit gas temp 4500°R (2230°C)

Power	860 kW
Voltage	205 volts
Impedance	79.5 to 83.0 mΩ
Weight Loss	8.5 g Total 0.0 g Exterior 8.5 g Bore 7.36 g MULE est MULE incremental Fig. 3
Appearance	Transverse cracks at 51
Pinholes	None

FIGURE 1
Coating Temperature

FIGURE 2
Coat Thickness

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-23
BNWL-934

ELEMENT 210 46219

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754
flat to flat .54 length

FORMULATION Loaded (213 mg/cc) standard ROVER mix Graphitized 4 hours
at 4540°R (2250°C)

LEACH BATCH B-2-22 Uranium Loss 4.41 g

COAT BATCH B-3-136 re-coat B-4-162 both G-end diffusion
Total coat weight 75.80 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A351 Total Mo weight 3.94 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach 10 psig air 60 cc/min (lot average 96
cc/min) incremental permeabilities Fig 3

ELECTRICAL TEST Underpressure 44-1/2 minute Helium pressure 30 psi below
hydrogen bore pressure at station 20 200 lbs H₂/hr no orifices
exit gas temp 4500°R (2230°C)

Power 885 kW
Voltage 211 volts
Impedance 82.0 to 85.0 mΩ
Weight Loss 11.9 g Total
0.0 g Exterior
11.9 g Bore
4.98 g MULE est
MULE incremental FIG 3

Appearance 'A' Flat 49-1/2 to 52-7/8
badly corroded

Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A - 24
BNWL - 934

ELEMENT 02-2051-90185

SOURCE: LASL (Experiment 50)

TYPE: 19 hole hexagonal, 0.110" dia. bores (machined), 0.752 - 0.754" flat to flat, 54" length.

FORMULATION: Loaded (210 mg/cc), 2 wt. % wood flour added to standard ROVER mix. Graphitized 4 hours at 4540°R (2250°C).

LEACH BATCH: B-2-22, Uranium loss: 3.96 g

COAT BATCH: B-3-136, recoat B-4-162, both G-end diffusion.
Total coat weight: 79.63 g
Coating temperature, Fig. 1; coating thickness, Fig. 2
Flow, B-3-136: 2.9 l/min/element; B-4-162: 2.85 l/min/element.
Run time, B-3-136: 14 hrs.; B-4-162: 4 hrs.

OVERCOAT: Not overcoated.

PERMEABILITY: Whole body before coating, 10 psig air: <1000 cc/min.

ELECTRICAL TEST: Not tested.

FIGURE 1
Coating Temperature

~~CONFIDENTIAL~~

ELEMENT 02-2051-90188

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal, 0.110" dia bores (machined) 0.752-0.754 flat to flat, 54 length

FORMULATION Loaded (210 mg/cc) 2 wt. % wood flour added to standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH B-2-22 Uranium loss 4.06 g

COAT BATCH B-3-136 recoat B-4-162, both G-end diffusion
Total coat weight 79.00 g
Coating temperature Fig 1, coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M2A350 Total Mo weight 3.06 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach 10 psig air >1000 cc/min Incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 30 min Overpressure <1-1/2 psi at inlet
no orifices 200 lbs H₂/hr exit gas temp 4500°R (2230°C)
Power 880 kW
Voltage 217 volts
Impedance 83.0 to 90.0 mΩ
Weight Loss 5.2 g Total
0.0 g Exterior
5.2 g Bore
4.76 g MULE est
MULE incremental Fig 3
Appearance Element parted at 7 3/4
Pinholes Intermediate

FIGURE 1
Coating Temperature FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

A-26
BNWL-934

ELEMENT 02 2051 90184

SOURCE LASL Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754 flat to flat 54 length

FORMULATION Loaded (210 mg/cc) 2 wt % wood flour added to standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)

LEACH BATCH B-2-22 Uranium loss 3.91 g

COAT BATCH B-3-136 re-coat B-4-162 both G-end diffusion
Total coat weight 80.87 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A350 Total Mo weight 3.46 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach, 10 psig air >1000 cc/min Incremental permeabilities Fig 3

ELECTRICAL TEST Phoebus 1B RPT 60 min, Overpressure, 1-1/2 psi at inlet no orifices 200 lbs H₂/hr, exit gas temp 4500°R (2230°C)
Power 991 kW
Voltage 217 volts
Impedance 86.0 to 92.0 mΩ
Weight Loss 7.7 g Total
0.0 g Exterior
7.7 g Bore
8.30 g MULE est
MULE incremental Fig 3
Appearance Good
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability and Weight Loss

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A-27
BNWL-934

ELEMENT 02 2051 90187

SOURCE LASL (Experiment 50)

TYPE 19 hole hexagonal 0.110 dia bores (machined) 0.752 0.754
flat to flat 54 length

FORMULATION Loaded (210 mg/cc) 2 wt % wood flour added to standard ROVER
mix Graphitized 4 hours at 4540⁰R (2250⁰C)

LEACH BATCH B 2 22 Uranium loss 3.96 g

COAT BATCH B-3-136 recoat B-4-162 both G end diffusion
Total coat weight 78.55 g
Coating temperature Fig 1 coating thickness Fig 2
Flow B-3-136 2.9 l/min/element B-4-162: 2.85 l/min/element
Run time B-3-136 14 hrs B-4-162 4 hrs

OVERCOAT Molybdenum coat batch M-2A350 Total Mo weight 3.15 g
Molybdenum coat thickness MULE est (g/5 increment) Fig 2

PERMEABILITY Whole body after leach 10 psig air >1000 cc/min Incremental
permeabilities Fig 3

ELECTRICAL TEST Underpressure 15 min Helium pressure 30 psi below hydrogen
pressure at station 20 200 lbs H₂/hr no orifices exit gas temp
4500⁰R (2230⁰C)

Power 900 kW
Voltage 218 volts
Impedance 81.5 to 86.5 mΩ
Weight Loss 4.6 g Total
0.0 g Exterior
4.6 g Bore
5.04 g MULE est
MULE incremental Fig 3

Appearance Corroded
Pinholes None

FIGURE 1
Coating Temperature

FIGURE 3
Incremental Permeability
and Weight Loss

~~CONFIDENTIAL~~

ELEMENT 02-2051-90183

SOURCE	LASL (Experiment 50)
TYPE	19 hole hexagonal, 0.110' dia bores (machined), 0.752-0.754 flat to flat 54" length
FORMULATION	Loaded (210 mg/cc), 2 wt. % wood flour added to standard ROVER mix Graphitized 4 hours at 4540°R (2250°C)
LEACH BATCH	B-2-22 Uranium Loss 3.69 g
COAT BATCH	B-3-136, recoat B-4-162, both G-end diffusion Total coat weight 80.24 g Coating temperature Fig 1 coating thickness, Fig 2 Flow, B-3-136 2.9 l/min/element B-4-162 2.85 l/min/element Run time, B-3-136 14 hrs B-4-162 4 hrs
OVERCOAT	Molybdenum coat batch M-2A350 Total Mo weight 3.46 g Molybdenum coat thickness, MULE est (g/5' increment) Fig 2
PERMEABILITY	Whole body after leach 10 psig air >1000 cc/min Incremental permeabilities Fig 3
ELECTRICAL TEST	Underpressure 30 min, Helium pressure 30 psi below hydrogen bore pressure at station 20. 200 lbs H ₂ /hr, no orifices exit gas temp 4500°R (2230°C)

Power	845 kW
Voltage	214 volts
Impedance	86.0 to 92.0 mΩ
Weight Loss	6.8 g Total 0.0 g Exterior 6.8 g Bore 5.64 g MULE est MULE Incremental Fig 3
Appearance	Transverse cracks
Pinholes	None

FIGURE 1
Coating Temperature FIGURE 2
Coat Thickness FIGURE 3
Incremental Permeability
and Weight Loss

UNCLASSIFIED

Distr-1
BNWL-934

DISTRIBUTION

No. of
Copies

OFFSITE

2	AEC Albuquerque Operations Office
2	AEC Albuquerque Operations Office Space Nuclear Propulsion Office Albuquerque Extension J. F. Cully H. Hessing
1	AEC Chicago Patent Group
1	AEC Chicago Patent Group G. H. Lee
1	AEC Library, Washington
1	AEC Library, Washington J. M. Morrissey
1	AEC-NASA Space Nuclear Propulsion Office, Nevada
1	AEC Nevada Operations Office
1	AEC Patent Office
2	Aerojet General Corporation, Sacramento (AEC)
1	Aerospace Corporation, Los Angeles (AF)
1	Air Force Air University Library
1	Air Force Foreign Technology Division
1	Air Force Headquarters
1	Air Force Strategic Air Command
1	Argonne National Laboratory (AEC)
1	Army Redstone Arsenal
2	Army White Sands Missile Range
1	Arc, Inc. (AF)
1	Atomics International (AEC)
1	Battelle Memorial Institute (AEC)
1	Bellcom, Incorporated (NASA)
1	Brookhaven National Laboratory (AEC)
1	Central Intelligence Agency
1	DOD-DASA-Sandia
2	Douglas Aircraft Corporation, MSSD (AF)

UNCLASSIFIED

UNCLASSIFIED

Distr-2
BNWL-934

No. of
Copies

1	duPont Company, Aiken (AEC)
1	EG&G, Inc., Goleta (AEC)
1	EG&G, Inc., Las Vegas (AEC)
1	General Dynamics/Fort Worth (AF)
1	General Electric Company, Cincinnati (AEC)
1	General Electric Company (AEC) (NASA)
1	Gulf General Atomic Incorporated (AEC)
1	Institute for Defense Analyses (ARPA)
1	Jet Propulsion Laboratory (NASA)
1	Johns Hopkins University (Navy)
2	Lawrence Radiation Laboratory, Livermore (AEC)
1	Lockheed-Georgia Company (NASA)
2	Los Alamos Scientific Laboratory (AEC)
2	Los Alamos Scientific Laboratory
	R. D. Baker
	D. P. MacMillan
1	NASA Goddard Space Flight Center
1	NASA Langley Research Center
6	NASA Lewis Research Center
6	NASA Lewis Research Center
	N. R. Thielke
1	NASA Manned Spacecraft Center
4	NASA Marshall Space Flight Center
3	NASA Scientific and Technical Information Facility
4	National Reactor Testing Station (Inc) (AEC)
1	Navy Air Systems Command
1	Navy Missile Center
1	Navy Office of the Chief of Naval Operations
2	Navy Ordnance Systems Command
1	Navy Radiological Defense Laboratory
1	Navy Ship Systems Command Headquarters
5	Oak Ridge National Laboratory (AEC)
1	Public Health Service (HEW)
1	Rand Corporation (AF)
1	Rocketdyne (AEC)
3	Sandia Corporation, Albuquerque (AEC)
1	TRW Systems (AEC)
1	Union Carbide Corporation (AEC)

UNCLASSIFIED

UNCLASSIFIED

Distr-3
BNWL-934

No. of
Copies

1 Union Carbide Corporation (Paducah Plant) (AEC)
1 Westinghouse Electric Corporation, Wal (AEC)
10 AEC Division of Technical Information Extension

4 AEC Division of Technical Information Extension
for Transmittal to:

Space Nuclear Propulsion Office
2100 Brookpark
Cleveland, Ohio 44135
L. Corrington

Union Carbide Corporation (ORNL) (OR)
J. M. Napier

Westinghouse Electric Corporation (NASA)
M. B. Blinn
H. Holmgren

ONSITE-HANFORD

1 AEC Chicago Patent Group
R. K. Sharp (Richland)

1 AEC Richland Operations Office
C. L. Robinson

1 Atlantic Richfield Hanford Company

2 Douglas United Nuclear

17 Battelle-Northwest
L. R. Bunnell
T. D. Chikalla
J. L. Daniel
D. R. de Halas
K. Drumheller
C. E. McNeilly
R. E. Nightingale
J. C. Spanner
G. L. Tingey
E. M. Woodruff
Technical Information Files (5)
Technical Publications (2)

UNCLASSIFIED