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Westinghouse Astronuclear Laboratory

JOINT WANL / LASL / Y-12
FUEL AND REACTOR DEVELOPMENT REVIEW
WANL - OCTOBER 11-12, 1966

Title Unclassified

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WANL-TME-1532

Westinghouse Astronuclear Laboratory

JOINT WANL / LASL / Y-12
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Classification cancelled (or changed to)
by authority of DOC.
by H.A.C. TIC, date SEP 10 1973

Prepared By.

W. P. Morris

NRX Project Engineering

SPECIAL REVIEW FINAL DETERMINATION	REVISIONS	CLASS	DATE
	JRP 4	U	4-15-82
Class: <u>U</u>			

INFORMATION CATEGORY	
<u>Confidential Restricted Data</u>	
<u>W.P. Morris</u>	<u>11/4/66</u>
AUTHORIZED CLASSIFIER	DATE

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WANL/LASL/Y-12 FUEL AND REACTOR DEVELOPMENT REVIEW

October 11-12, 1966

WANL

Tuesday, October 11, 1966

Opening Remarks

1. NRX-A4/A5 REACTOR TEST RESULTS

Introduction	F. D. Retallick
Reactor Observations and Performance	L. Boman
Post-Run Reactor and Fuel Element Observation and Analysis	J. G. Gallagher
Fuel Element Observation and Correlation	A. Boltax
Summary of What Was Learned	F. D. Retallick

2. FUEL PROGRAM

Introduction	W. H. Esselman
Fuel Assessment	
Electrical Test Performance	E. A. DeZubay
Screening Test	J. C. Guzek
Post-Test Destructive Analysis	M. B. Blinn
Fuel Development	
Introduction	W. R. Ellis
Result of Matrix Permeability Reduction Program	J. D. Holmgren
Y-12 Results on Matrix and Coating	F. Tench
Phases III and IV Fuel Development	A. Boltax

Wednesday, October 12, 1966

3. LASL

Summary of Hot Gas Test Results

LASL Coating Development Program

Graphite Developments - Carbide Composites

Test Data on Carbide Composite Hot Ends for
Fuel Elements and Support Systems

LASL Fuel Element Test Program for the Next
Three to Four Months

LASL Summary

R. L. Petty

M. G. Bowman

J. M. Taub

L. L. Lyon

D. P. MacMillan

R. W. Spence

4. REACTOR DESIGN EFFECTS ON FUEL PERFORMANCE

Introduction

Design Features and Mechanical Improvements

Thermal and Nuclear Analysis

Gas Injection

Summary

H. S. McCreary

W. G. Brussalis

R. R. Holman

F. T. Johnson

W. G. Roman

5. TECHNICAL RECOMMENDATIONS AND PREDICTIONS

W. H. Esselman

6. PROGRAM PLANNING AND RECOMMENDATIONS

H. F. Faught

INTRODUCTION

F. D. Retallick

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NRX TEST RESULTS

1. A BRIEF DESCRIPTION OF THE REACTORS AND THE ENVIRONMENT TO WHICH THE FUEL ELEMENTS WERE EXPOSED IN NRX-A3, A4, AND A5.
2. WHAT DID WE LEARN ABOUT THE BEHAVIOR OF THE FUEL AND CORE OF THE NRX REACTORS WITH RESPECT TO:
 - (A) LOCATION OF THE FUEL IN THE ASSEMBLY, OR THE EFFECT OF THE ENVIRONMENT TO WHICH IT WAS SUBJECTED.
 - (B) PINHOLING PERFORMANCE AND ITS EFFECT.
 - (C) WEIGHT LOSS - BORE AND SURFACE.
 - (D) FUEL ELEMENT END PERFORMANCE.
 - (E) STRUCTURAL INTEGRITY.
3. WHAT DID WE LEARN FROM DETAIL EXAMINATION OF THE FUEL ELEMENTS THAT COULD EXPLAIN THE PERFORMANCE NOTED AND LEAD TO DIRECTIONS OF IMPROVEMENT ?

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NRX TEST RESULTS

	<u>NRX-A3</u>	<u>NRX-A4</u>	<u>NRX-A5</u>
APPROXIMATE RUN TIME	15 MINUTES	30 MINUTES	30 MINUTES
PART POWER OPERATION	45-50 MINUTES	84 MINUTES	9 MINUTES
CYCLES	3	11	2
COMPLETE CORE DISASSEMBLY	JUNE 20, 1965	APRIL 21, 1966	AUGUST 15, 1966
ELEMENTS WEIGHED	1096	1250	1551
ELEMENTS INCREMENTALLY WEIGHED	32	41	66
ELEMENTS SLICED	89	70	43
ELEMENTS MEASURED FOR SURFACE LOSS	100	120	127

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REACTOR OBSERVATIONS AND PERFORMANCE

L. Boman

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REACTOR CORE DESCRIPTION AND PERFORMANCE

CORE ASSEMBLY

FILLER STRIPS

SUPPORT BLOCKS

FUEL ELEMENTS

CORE AND FUEL ELEMENT ENVIRONMENTAL CONDITIONS

GROSS TEST PROFILES

TEMPERATURE DIAGNOSTIC DATA

ENVIRONMENTAL CONDITIONS BY REGION

SUMMARY

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NRX-A CORE ASSEMBLY

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CONFIDENTIAL **COLD PERIPHERY FILLER STRIPS****CONFIDENTIAL**

HOT BUFFER FILLER STRIP SUPPORT ARRANGEMENT

COLD PERIPHERY FILLER STRIP SUPPORT ARRANGEMENT

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CONFIDENTIAL **SUPPORT BLOCK NRX-A4** **FOIL WASHER DESIGN NRX-A5**

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NRX-A5 SKIRTLESS BLOCK EXPERIMENT

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PARTIAL UNFUELED ELEMENT

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NRX-A5 AND NRX/EST GROSS CHARACTERISTICS OF FUEL ELEMENT

	NRX/EST		NRX-A5	
	AFF	Y-12	AFF	Y-12
LOADING CODE 9 ELEMENTS				
AVG. URANIUM, GRAMS	126.293	127.729	126.377	127.572
AVG. NIOBIUM, GRAMS	43.3	50.1	59.133	58.316
AVG. CARBON, GRAMS	527.420	527.182	526.652	534.446
NbC THICKNESS AT STA. 20, AVG, MILS	1.05	1.20	1.76	1.43
NbC THICKNESS AT STA. 45, AVG, MILS	1.77	1.80	2.08	2.00

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COMPARISON OF NOZZLE CHAMBER TEMPERATURE PROFILES

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NRX KEY ENVIRONMENTAL CONDITIONS

	NRX-A3	NRX/EST	NRX-A5
EQUIVALENT FULL POWER RADIATION (MIN.)	26.8	54.4	30.0
MAXIMUM FLOW RATE (LB/SEC)	73.5	87.9	71.9
MAXIMUM POWER (MW)	1100	1155	1120
NUMBER OF STARTUPS AND SHUTDOWNS	3	11	2
MAXIMUM STARTUP RAMP (°R/SEC)	+80	+140	+70
MAXIMUM SHUTDOWN RAMP (°R/SEC)	-130	-141	-80
MAXIMUM BERYLLIUM TEMPERATURE BEFORE STARTUP (°R)	589	645	575

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NRX TEMPERATURE HISTORY

	NRX/EST			NRX-A5		
	<u>NOZZLE CHAMBER</u>	<u>STA. 26</u>	<u>STA. 20</u>	<u>NOZZLE CHAMBER</u>	<u>STA. 26</u>	<u>STA. 20</u>
TIME (MINUTES) WITHIN TEMPERATURE INTERVAL						
1900 - 2000°R	29.3	1.3	1.5	1.5	0.1	0.2
2000 - 2500°R	15.5	9.7	4.9	0.7	0.7	0.9
2500 - 2900°R	7.7	2.1	13.7	0.7	0.6	1.5
2900 - 3200°R	0.6	10.6	14.0	0.5	0.7	11.9
3200 - 3400°R	7.0	2.4	12.8	0.6	0.6	18.5
3400 - 3600°R	6.0	8.6	-	0.4	1.7	-
3600 - 3700°R	0.2	7.1	-	0.7	4.4	-
3700 - 3800°R	3.6	0.7	-	0.7	18.2	-
3800 - 3900°R	6.1	12.8	-	3.0	6.4	-
3900 - 4000°R	5.3	-	-	11.3	-	-
4000 - 4100°R	7.3	-	-	12.8	-	-
4100 - 4200°R	7.8	-	-	2.3	-	-

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NRX-A5 EP-IV CORE STATION 20 TEMPERATURE MEASUREMENTS

CONFIDENTIAL **NRX-A5 EP-IV CORE STATION 26 TEMPERATURE MEASUREMENTS****CONFIDENTIAL**

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NRX-A5 EP-IV CORE STATION 26 TEMPERATURE MEASUREMENTS

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CALCULATED SENSOR TO FUEL TEMPERATURE DIFFERENCE FOR NRX-A5 AT FULL POWER CONDITIONS

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NRX-A5 EP-IV PARAMETRIC VARIATION

POWER, FLOW, CORE PRESSURE DROP AND SEAL PRESSURE
DIFFERENCE VERSUS TIME

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NRX/EST AND NRX-A5 CONTROL DRUM POSITION DURING OPERATION ABOVE 3800°R CHAMBER TEMP

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QUARTER CROSS SECTION OF CORE REGIONS OF DISCUSSION

NRX/EST NOMINAL RADIAL POWER DISTRIBUTION

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AXIAL TEMPERATURE DISTRIBUTION NRX/EST EP IV A CENTRAL REGION

START OF LIFE

END OF LIFE

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AXIAL TEMPERATURE DISTRIBUTION NRX/EST EP IV A TROUGH REGION

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NRX/EST EP-IV A PERIPHERAL REGION

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NRX-A5 EP-IV SOL PERIPHERAL REGION

NRX-A5 EP-IV EOL PERIPHERAL REGION

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POST-RUN REACTOR AND FUEL ELEMENT OBSERVATION AND ANALYSIS

J. G. Gallagher

POST-RUN CORE AND FUEL ELEMENT OBSERVATIONS AND CORRELATIONS

GROSS CORE OBSERVATIONS

FILLER STRIP OBSERVATIONS

SUPPORT BLOCK OBSERVATIONS

FUEL ELEMENT TOTAL WEIGHT LOSS AND OBSERVATIONS

TOTAL WEIGHT LOSS VALUES

DISTRIBUTION

COMPOSITION OF WEIGHT LOSS

WEIGHT LOSS AS A FUNCTION OF TIME

WEIGHT LOSS BEHAVIOR IN THE 5F4 AND 5F5 REGION

SURFACE WEIGHT LOSS AND PINHOLES

INCREMENTAL WEIGHT LOSS

CORRELATION OF FUEL ELEMENT WEIGHT LOSS

COMPARISON OF ELEMENT PERFORMANCE IN REACTOR WITH ELECTRICAL TEST

IDENTIFICATION OF CAUSE OF DEVIATION FROM PREDICTION

SUMMARY

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CORE AFT FACE NRX-A5

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NRX-A5 SIDE OF CORE

REGULAR FILLER STRIPS

HOT BUFFER REGION FILLER STRIPS

AFT END

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NRX-A5 HOT BUFFER FILLER STRIP BREAKAGE TABULATION

	FORWARD END	STATION 20 TO 49	AFT END	TOTAL
NUMBER OF FILLER STRIPS BROKEN	19	15	5	39
NUMBER OF FILLER STRIP BREAKS	19	46	5	70

TOTAL NUMBER OF FILLER STRIPS IN HOT BUFFER REGION = 54

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**NRX-A5 HOT BUFFER FILLER STRIP
CORROSION
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← AFT

NRX/EST

NRX-A5

**SUPPORT BLOCK CROSS SECTION
IN NRX/EST AND NRX-A5**

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**NRX/EST IRREGULAR SUPPORT
BLOCK SHOWING CRACKED
LOBES AND SKIRTS**

**NRX-A5 IRREGULAR SUPPORT BLOCK
SHOWING THE LESS SEVERE CRACKING
WHICH OCCURRED**

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NRX-A6 REZONED CORE, AXIAL PROFILE OF BORE TO INTERSTITIAL PRESSURE DIFFERENCE

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NRX/EST FUEL ELEMENT WEIGHT LOSS

	CENTRAL REGION 0-9"		MID RADIAL REGION 9"-14"		PERIPHERAL REGION 14"-17"	
	<u>AFF</u>	<u>Y-12</u>	<u>AFF</u>	<u>Y-12</u>	<u>AFF</u>	<u>Y-12</u>
TOTAL NO. OF FUEL ELEMENTS	0	426	357	267	534	0
NUMBER BROKEN	-	39	53	7	40	-
MEASURED AVERAGE WEIGHT LOSS OF BROKEN ELEMENTS	-	47.3	71	17.8	58.1	-
MEASURED AVERAGE WEIGHT LOSS OF INTACT ELEMENTS	-	14.5	30.1	11.6	29.2	-
DEVELOPED OVERALL AVERAGE WEIGHT LOSS	-	18.9	46.9	11.88	43.7	-

OVERALL AVERAGE 32.4 GRAMS/ELEMENT

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NRX-A5 FUEL ELEMENT WEIGHT LOSS

	CENTRAL REGION 0-9"		MID RADIAL REGION 9"-14"		PERIPHERAL REGION 14"-17"	
	<u>AFF</u>	<u>Y-12</u>	<u>AFF</u>	<u>Y-12</u>	<u>AFF</u>	<u>Y-12</u>
TOTAL NO. OF FUEL ELEMENTS	324	102	29	595	486	48
NUMBER BROKEN	250	13	18	38	13	307
MEASURED AVERAGE WEIGHT LOSS OF BROKEN ELEMENTS	56.0	41.0	32.3	26.4	34.1	32.2
MEASURED AVERAGE WEIGHT LOSS OF INTACT ELEMENTS	30.8	17.5	16.8	13.7	17.0	17.6
DEVELOPED OVERALL AVERAGE WEIGHT LOSS	46.5	20.5	23.1	14.7	26.4	21.9

OVERALL AVERAGE 27.0 GRAMS/ELEMENT

FIGURE 3.12

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NRX-A6 CLUSTER SUPPORT WITH TUNGSTEN DESIGN CUPS

CAPING SAMPLING CONDITIONS

	<u>CENTRAL REGION</u>	
CASE	1	2
NO. OF PINHOLE	4 (EQUIV. 16)	4 (EQUIV. 16)
LOCATION OF PINHOLE, STATION	20, 28, 36, 44	20, 28, 36, 44
AVERAGE ORIFICE SIZE, MIL	60	60
AVERAGE INITIAL INTERELEMENT GAP, MILS	0.2 TO 1.8	0.17 TO 4.0

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**SURFACE REGRESSION AT 13.5 MIN.
4 PINHOLES AT STATION 20, 28, 36, AND 44.**

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ELEMENT SURFACE MATERIAL LOSS DEFINITIONS

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NRX-A3 ESTIMATED DIVISION OF SURFACE AND BORE WEIGHT LOSS

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NRX/EST ESTIMATED DIVISION OF FUEL ELEMENT BORE AND SURFACE WEIGHT LOSS

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NRX-A5 ESTIMATED DIVISION OF FUEL ELEMENT BORE AND SURFACE WEIGHT LOSS

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CALCULATED AND MEASURED REACTIVITY LOSS DURING NRX/EST TESTING

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NRX/EST INCREMENTAL WEIGHT LOSS

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NRX-A5 INCREMENTAL WEIGHT LOSS

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AXIAL DISTRIBUTION OF INCREMENTAL WEIGHT LOSS NRX-A3

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AXIAL DISTRIBUTION OF INCREMENTAL WEIGHT LOSS NRX-A5

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AXIAL DISTRIBUTION OF INCREMENTAL WEIGHT LOSS NRX/EST

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EFFECT OF ELEMENT POROSITY ON CORE STATION 20 PRESSURES FOR NRX/EST EOL

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CORRELATION PARAMETERS

DEPENDENT VARIABLES

ELEMENT TOTAL WEIGHT LOSS, OR
ELEMENT INCREMENTAL WEIGHT LOSS

INDEPENDENT VARIABLES

ENVIRONMENTAL FACTORS

1. BORE-TO-BORE PRESSURE DIFFERENCE
2. BORE-TO-INTERSTITIAL PRESSURE DIFFERENCE
3. CHANNEL REYNOLDS NUMBER*
4. CHANNEL WALL TEMPERATURE*
5. TEMPERATURE DIFFERENCE IN FUEL FROM HOT SPOT TO WALL *
6. ELEMENT AVERAGE POWER FACTOR
7. ELEMENT AVERAGE ORIFICE SIZE

PHYSICAL PROPERTIES OF ELEMENT

8. AS-LEACHED (BEFORE BORE COATING) BODY PERMEABILITY**
9. COATING THICKNESS
10. AFTER BORE COATING BODY PERMEABILITY
11. FUEL LOADING

OTHER FACTORS

12. RADIUS FROM CORE CENTERLINE
13. AVERAGE WEIGHT LOSS FOR COATING BATCH

* USED FOR INCREMENTALS ONLY

** USED FOR NRX-A5 TOTAL WEIGHT LOSSES ONLY

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NRX-A6 OPERATING REACTIVITY LOSS BASED ON A SEMI-QUANTITATIVE ADJUSTMENT OF REACTOR DATA BY ELECTRICAL TEST DATA.

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FUEL ELEMENT OBSERVATION AND CORRELATION

A. Boltax

OUTLINE

Fuel Element Observations and Correlations

- A. Examine known differences between Y-12 and WAFF fuel elements.
- B. Compare performance of Y-12 and WAFF fuel elements in NRX-A4 and A5.
- C. Relate known differences between Y-12 and WAFF fuel elements to fuel element performance.
- D. Conclusions

KNOWN DIFFERENCES BETWEEN Y-12 AND WAFF FUEL ELEMENTS

A. MATRIX

1. Matrix processing (extrusion, cure, and bake)
2. Matrix leak rate data

	Incremental Leak Rate (He, cc/min.)	
	<u>As-leached</u>	<u>As-coated</u>
WAFF	20-30	5-15
Y-12	0-15	0-5

3. Matrix thermal expansion ($\times 10^{-6}$ per $^{\circ}\text{C}$) at 1900°C

	<u>Axial</u>	<u>Transverse</u>
WAFF	4.5	4.5 (4.2-4.8)
Y-12	4.5	5.2 (4.9-5.4)

B. COATING

1. Coating process (temperature, chemistry, and flow rates)
2. Matrix - coating adherence
3. NbC crack distribution

		Average Number of Cracks/Inch				
		Position				
		<u>No.</u>	<u>20"</u>	<u>Range</u>	<u>35"</u>	<u>Range</u>
WANL	A4	14	60	30-104	22	7-22
	A5	9	24	7-44	19	31-91
Y-12	A4	11	86	62-110	70	38-101
	A5	4	78	75-83	49	23-66

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TYPICAL
WANL

A4

A5

TYPICAL
Y-12

A4

A5

COMPARISON OF A4 & A5 CRACK PATTERNS @ STATION 20
200X

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OUTLINE

Comparison of Performance of Y-12 and WAFF Fuel Elements in NRX-A4 and A5

- A. Gross Behavior
 - 1. Overall core performance
 - 2. Examination of broken elements
 - 3. Pinholing
 - 4. End behavior

- B. Detailed Examination
 - 1. Incremental weight loss
 - 2. Batch behavior
 - 3. Electrical vs. reactor correlations
 - 4. Influence of bore to interstitial gap pressure on bore corrosion
 - 5. Effects of bead type of fuel performance
 - 6. Correlations between fuel performance and fuel element processing
 - 7. Examination of Mo overcoated elements

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AVERAGE WEIGHT LOSS INDEX OF PERFORMANCE FOR WAFF
BORE COATING BATCHES IN NRX-A5

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FLEXURE STRENGTHS IN NRX-A5

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FLEXURE STRENGTHS IN NRX-A5

AXIAL STATION (INCHES)

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Fuel Element End Behavior in NRX-A4 and NRX-A5

Element Type		Region	Avg. BAR	Per Cent of Elements with	
				Joint Corrosion	51-52" Damage
A-4					
WAFF	1/4"	H-J	95	15	60
	O. D. 1/4"	Periphery	95	15	65 (end)
	Tapered		99	0	15 (end)
Y-12	1"	O, A, B	60	20	100
	1"	Junction	71	30	100
A-5					
WAFF	1"	O-D, H-J	99	< 3	< 3
Y-12	1"	E-H	99	< 3	< 3
	Brazed		99	< 3	< 3

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NRX-A4 AVERAGE P+H PER ELEMENT

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(CALCULATED ON 3" INTERVALS)

NRX A-4 AXIAL PINHOLE DISTRIBUTION

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NRX A-5 AXIAL PINHOLE DISTRIBUTION

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NRX-A5 INCREMENTAL WT. LOSS - BATCH C271/L159

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NRX-A5 AVERAGE INCREMENTAL WEIGHT LOSS - BATCH M-49

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MAX. INCREMENTAL WEIGHT LOSS VS NbC THICKNESS IN MID-BAND REGION

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Summary of NRX-A4 and A5 Incremental Fuel Element Weight Loss

	Element Type	NbC Coating Thickness (mils)		Avg. Total Wt. Loss (gms)	Incremental Wt. Loss (grams/inch)		Reactor Location
		at 20"	at 40"		Mid-band	Hot End	
A-4							
WAFF	1 step coating	1.0	1.6	30	0.5-1.0	Bore corrosion	Trough
	2 step coating	1.0	1.6	30	0.6	Bore corrosion	Trough
	O. D. coating	1.0	1.6	30	0.8	Bore corrosion	Periphery
Y-12	2 step coating	1.2	1.8	12	0.4-0.8	0.1-0.4	Trough
		1.2	1.8	35	0.5-1.0	Surface corrosion	Center
A-5							
WAFF	2 step coating	1.7	2.0	20-30	2.0-6.0	0.2-0.4	Trough
		1.7	2.0	40-70	3.0-8.0	0.2-1.7	Center
	1 step (M49)	2.0	2.3	14	1.4	0.2	Trough
	O. D. coating	1.7	2.0	15 U*, 25 B*	1.8-6.0	0.2-0.4	Periphery
		1.7	2.0	7-12	1.4	0.2	Best periph- eral element
Y-12	2 step	1.4	2.0	10-17	0.8-3.0	0.1-0.8	Trough
	2 step (LASL)	1.8	2.1	10	0.8-2.2	0.3-0.4	Trough

* U - unbroken, B - broken

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NRX-A5 - ΔW VS. R FOR FUEL ELEMENTS FROM BATCH
C271/L159 - CODE 99 - GA BEADS

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NRX-A5 - ΔW VS. R FOR FUEL ELEMENTS FROM BATCHES C282/F243, C282/L172

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CONFIDENTIAL NRX-A5 ΔW VS. R FOR FUEL ELEMENTS FROM Y-12 BATCH 944W/044W - CODE 99

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NRX-A5 - ΔW VS. R FOR FUEL ELEMENTS FROM BATCH 943W/043W - CODE 99

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AVERAGE WEIGHT LOSS INDEX OF PERFORMANCE FOR Y-12
BO-E COATING BATCHES IN NRX-A5

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AVERAGE WEIGHT LOSS INDEX OF PERFORMANCE FOR WAFF C FURNACE BORE
COATING BATCHES IN NRX-A5

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FLEXURE STRENGTHS IN NRX-A5 ELEMENTS

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Examination of NRX-A5 Fuel Element Performance by Bead Type and Loading

<u>Type</u>		<u>Code</u>	<u>No.</u>	<u>Figure of Merit</u>	<u>Per Cent Broken</u>
WAFF	GA	39	97	1.29	62
	CP	39	6	1.39	33
	GA	49	58	1.13	37
	GA	59	36	0.88	58
	3M	69	94	0.91	44
	3M	79	77	1.38	85
	3M	89	85	1.41	94
	GA	99	336	1.05	77
	CP	99	24	1.13	88
Y-12	GA	99	488	0.99	10
	CP	99	24	1.06	10

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TWO ELEMENT
WERE BONDED

ELEMENTS SURROUNDING 3J9R (MO COATED); CHANNEL EXPOSURE ON 3J9R WAS OBSERVED ON CORNER AF 23-24 INCHES, DE 22-23 INCHES. NOTABLE SURFACE OCCURED ON FLATS A,E, AND F IN THE VICINITY OF THE FUEL ELEMENT BREAK AT 22 INCHES.

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NRX-A5 - ΔW FOR Mo COATED ELEMENTS AND NEIGHBORS

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SURFACES OF NRX-A5 MO COATED ELEMENT
3J9R (TOP D-E FACES) AND NEIGHBORING ELEMENT
3J9W (BOTTOM A-B FACES) AT STATIONS 22-23
(COLD ENDS TO LEFT)

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CHANNELS IN NRX-A5 ELEMENT 3J9W
NEIGHBOR TO 3J9R Mo COATED ELEMENT

#3 CHANNEL

#6 CHANNEL

#10 CHANNEL

#14 CHANNEL

#17 CHANNEL

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#3 CHANNEL

#6 CHANNEL

#10 CHANNEL

#14 CHANNEL

#17 CHANNEL

CHANNELS IN NRX A-5 ELEMENT 3J9S
NEIGHBOR TO 3J9R Mo COATED ELEMENT

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1-81

BREAK AT $22\frac{1}{2}''$

#3 CHANNEL

#6 CHANNEL

#10 CHANNEL

#14 CHANNEL

#17 CHANNEL

CHANNELS IN NRX-A5 Mo COATED ELEMENT 3J9R

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#3 CHANNEL

#6 CHANNEL

#10 CHANNEL

#14 CHANNEL

#17 CHANNEL

CHANNELS IN NRX-A5 Mo COATED ELEMENT 3J9R

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SCHEMATIC COMPARISON OF REACTOR AND ELECTRICAL TEST INCREMENTAL WEIGHT LOSS

(IN THE ABSENCE OF SURFACE CORROSION)

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HOT END WEIGHT LOSS VS ELECTRICAL TEST TIME 760 KW

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MID BAND WEIGHT LOSS VS ELECTRICAL TEST TIME

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Schematic Summary of Y-12 and WAFF Behavior
in NRX-A4 and A5

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SUMMARY OF WHAT WAS LEARNED

F. D. Retallick

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THINGS LEARNED FROM ANALYSIS OF NRX-A3, A4, AND A5
ABOUT CORE AND FUEL PERFORMANCE

<u>PROGRAM</u>	<u>OBSERVATION OR FACT LEARNED</u>
DESIGN	1. OBSERVATIONS OF SOOTING PATTERNS ON THE AFT FACE OF THE CORE, IN-CORE THERMOCOUPLE BEHAVIOR, DISTRIBUTED SEAL PRESSURE PATTERNS, AND REACTIVITY CHANGES CAN BE USED AS INDICATORS OF CORE DAMAGE.
DESIGN	2. ALTHOUGH SMALL GAPS ARE DESIRABLE BETWEEN FILLER STRIPS TO PREVENT CORROSION, BREAKAGE MAY RESULT UNLESS CONSIDERABLE DETAIL TRANSIENT ANALYSIS IS PERFORMED.
DESIGN	3. QUALITATIVE EVALUATION OF THE ANALYTICAL AND TESTING TOOLS USED TO DETERMINE SUPPORT BLOCK STRESS VALUES HAS BEEN ACHIEVED.
DESIGN	4. MORE ADHERENT COATINGS OR MATERIALS LESS SUSCEPTIBLE TO CORROSION ARE NEEDED FOR SUPPORT BLOCKS FOR A RELIABLE 60 MINUTE REACTOR.

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THINGS LEARNED FROM ANALYSIS OF NRX-A3, A4, AND A5
ABOUT CORE AND FUEL PERFORMANCE

(PAGE 2)

<u>PROGRAM</u>	<u>OBSERVATION OR FACT LEARNED</u>
DESIGN	5. THE UNFORTUNATE PLUGGING OF ORIFICE AND CLUSTER PLATES IN NRX-A5 AFFORDED AN UNDERSTANDING OF CLUSTER FAILURE MECHANISMS FOR APPROXIMATELY 15 MINUTES OF OPERATION.
DESIGN	6. UNFUELED ELEMENT ENDS WITH ESSENTIALLY NO UNDERCUT RESULT IN EXCELLENT END BEHAVIOR.
FUEL EVALUATION AND DESIGN	7. ELEMENT WEIGHT LOSS HAS A CORE RADIAL POSITION DEPENDENCE AND MUST BE SEGREGATED AS TO SURFACE AND BORE LOSS IN ORDER TO GAIN INSIGHT INTO THE REASONS.
FUEL EVALUATION & FUEL DEVELOPMENT	8. FUEL ELEMENTS MADE BY TWO PLANTS TO THE SAME SPECIFICATION AND ACCEPTED WITH LITTLE PERFORMANCE DIFFERENCE IN THE ELECTRICAL FURNACE TESTS SHOW A SIGNIFICANT AVERAGE PERFORMANCE DIFFERENCE AT THE END OF LIFE.
FUEL EVALUATION & FUEL DEVELOPMENT	9. FUEL ELEMENT BORE WEIGHT LOSS IS NOT LINEAR WITH TIME PUT PROCEEDS AT AN INCREASING RATE WITH TIME, AND APPEARS HIGHER THAN THE STANDARD ELECTRICAL CORROSION TEST; ESPECIALLY FOR WAFF ELEMENTS.

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THINGS LEARNED FROM ANALYSIS OF NRX-A3, A4, AND A5
ABOUT CORE AND FUEL PERFORMANCE

(PAGE 3)

<u>PROGRAM</u>	<u>OBSERVATION OR FACT LEARNED</u>
DESIGN	10. THERE ARE INDICATIONS, SPECIFICALLY IN THE PERIPHERY, THAT FINE GRAIN PHYSICAL LOCATION IN THE CORE AFFECTED THE ELEMENTS' PERFORMANCE.
FUEL EVALUATION & FUEL DEVELOPMENT	11. PINHOLING OCCURS IN THE REACTOR AT CONSIDERABLY SHORTER TIMES, AND IN MUCH GREATER QUANTITY THAN IN THE STANDARD ELECTRICAL CORROSION TEST AND IS THE PRIMARY CAUSE OF SURFACE CORROSION IN THE REACTOR.
FUEL DEVELOPMENT	12. SPECIFIC COATING BATCHES PERFORMED ABOVE OR BELOW AVERAGE IN THE REACTOR AND SERVE AS A BASIS FOR ISOLATING IMPORTANT COATING PARAMETERS.
FUEL DEVELOPMENT	13. ELEMENTS WITHIN A COATING BATCH AND BORES WITHIN AN ELEMENT FOR 30 MINUTES OF REACTOR TESTING SHOW A LARGE VARIATION IN PERFORMANCE.

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THINGS LEARNED FROM ANALYSIS OF NRX-A3, A4, AND A5
ABOUT CORE AND FUEL PERFORMANCE

(PAGE 4)

PROGRAM

OBSERVATION OR FACT LEARNED

FUEL EVALUATION &
FUEL DEVELOPMENT

14. THE THICKER COATING ON THE WAFF ELEMENTS
AT THE MIDRANGE RESULTED IN MORE SEVERE
CORROSION AT THAT LOCATION, BUT WAS NOT
DETECTED IN THE STANDARD ELECTRICAL TEST.

FUEL EVALUATION &
FUEL DEVELOPMENT

15. THE TWO MOLYBDENUM COATED FUEL ELEMENTS
IN NRX-A5 VERIFY THE REDUCTION IN MIDRANGE
CORROSION OBSERVED IN THE STANDARD ELECTRICAL
TEST BUT DO NOT SEEM TO CONFIRM THE FURNACE
OBSERVATION OF PINHOLING AND INCREASED
WEIGHT LOSS DOWNSTREAM OF THE COATING.

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1-89

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NRX-A5 WEIGHT LOSS AT 3 IN. RADIUS

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FUEL PROGRAM

INTRODUCTION

W. H. Esselman

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REACTOR DEVELOPMENT PROGRAM

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ELECTRICAL TEST PERFORMANCE

E. A. DeZubay

FUEL ASSESSMENT PROGRAM PHASE I AND II SUMMARY

<u>PHASE</u>	<u>REACTOR APPLICABILITY</u>	<u>SOURCE</u>	<u>BORE TO EXTERNAL OVERPRESSURE</u>	<u>EXTERNAL BORE TO OVERPRESSURE</u>	<u>HIGH POWER</u>	<u>NOMINAL POWER (760 KW)</u>	
I-1A	NRX-A6	WANL	X			X	SOURCE DIFFERENCES, P EFFECTS. MOLYBDENUM OVERCOAT EFFECTS. POROSITY EFFECTS
I-1B	NRX-A6	Y-12	X			X	
I-1C	NRX-A6	MIXED	X			X	
I-2A	NRX-A4, 5	MIXED	X			X	CHARACTERIZATION OF NRX-A4 AND NRX-A5 ELEMENTS.
I-2B	NRX-A4, 5	MIXED				X	
I-2C	NRX-A4, 5	MIXED				X	
I-2D	NRX-A4, 5	MIXED	X	X	X		
I-2E	NRX-A4, 5	MIXED	X				
I-3A	PHOEBUS 1B	MIXED	X	X	X		CHARACTERIZATION TESTS
I-4A	NRX-A4, 5	MIXED	X	X	X		SCREENING TEST BEHAVIOR
II-1B							
ORIFICE POWER	NRX-A6	Y-12	X			X	VARIATION OF TEST PARAMETERS
& FLOW	NRX-A6	Y-12	X		X		
CYCLIC	NRX-A6	Y-12	X			X	

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NOMINAL PRESSURE AND TEMPERATURE RELATIONS FOR HYDROGEN CORROSION TESTS

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AXIAL FAILURE LOCATION VARIED BY PRESSURE DIFFERENCE

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TIME TO FAILURE OF ELECTRIC PRESSURE DIFFERENCE TEST

FUEL ELEMENT BORE PRESSURE - FURNACE HELIUM
ATMOSPHERE PRESSURE AT FUEL ELEMENT STATION 20

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NUMBER OF PINHOLES VS TEST TIME (LITTLE OR NO SURFACE CORROSION)

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2-5A

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PHASE II-1B(CYCLIC BEHAVIOR) BATCH 76

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POWER FLOW-POWER DENSITY TESTS

GROUP I - SIMULTANEOUS INCREASE IN POWER AND FLOW AT CONSTANT
HEATED LENGTH OF ELEMENT

F (SCFM)	POWER (KW)	L (HEATED LENGTH)	POWER DENSITY (KW/IN)
690	1050	48	21.8
595	905	48	18.9
500	760	48	15.8

GROUP II - CONSTANT POWER AND FLOW WITH SHORTENED HEATED LENGTH

500	760	48	15.8
500	760	40	19.0
500	760	36	21.2

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**WEIGHT LOSS VS TIME
PHASE II-1B
77 PSI PRESSURE DIFFERENCE AT STATION 20
Y-12, A5 ELEMENTS
BATCH 8994W**

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**7 PSI PSI PRESSURE DIFFERENCE AT STATION 20 Y-12,
AVERAGE WEIGHT LOSS PER INCH VS vs. TIME PHASE II-1B
A5 ELEMENTS BATCH 8994W**

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WEIGHT LOSS VS. TIME NRX-A4 CHARACTERIZATION A4 ELEMENTS (760 KW)

WEIGHT LOSS VS. TIME NRX-A5 CHARACTERIZATION A5 ELEMENTS (760 KW)

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TEST SPECIFICATION 1-2D 30 PSI PRESSURE DROP AT FUEL ELEMENT STATION 20 ($\Delta P_{20} = 30$ PSI)

<u>FFL TEST NUMBER</u>	<u>FUEL ELEMENT SERIAL NUMBER</u>	<u>FUEL ELEMENT IDENTIFICATION</u>	<u>TIME AT POWER MINUTES</u>	<u>WEIGHT LOSS GRAMS</u>	<u>PINHOLES NUMBER</u>	<u>WEIGHT LOSS RATE GRAMS/MINUTE</u>
2106	AC 99-20561	A4 TYPICAL	13.33	9.0	15	0.68
2107	AC 99-20578	A4 TYPICAL	15.00	9.5	23	0.63
2108	AC 99-21910	A4 TYPICAL	18.87	8.7	64	0.46
1.b. 2.0003	AC 99-28436	A5 TYPICAL	13.08	7.4	34	0.57
1.b. 2.0004	AC 99-28437	A5 TYPICAL	FAILURE AT START		0	
1.b. 2.0005	AC 99-28380	A5 TYPICAL	16.83	8.6	3	0.51
1.b. 2.0006	UN 99-73855	Y-12, A5 TYPICAL	20.00	12.2	0	0.61
1.b. 2.0007	UN 99-73824	Y-12, A5 TYPICAL	24.72	13.7	1	0.55
1.b. 2.0011	UN 99-73819	Y-12, A5 TYPICAL	25.90	14.9	15	0.57
1.b. 2.0008	UN 99-96491	Y-12, A4 TYPICAL	20.00	14.0	0	0.70
1.b. 2.0009	UN 99-96601	Y-12, A4 TYPICAL	27.25	15.1	38	0.56
1.b. 2.0010	UN 99-96438	Y-12, A4 TYPICAL	12.88	17.6	66	1.37
1/2 PSI HELIUM OVERPRESSURE						
1.b. 2.0012	UN 99-73812	Y-12, A5 TYPICAL	25.30	16.8	1	0.66
1.b. 2.0013	UN 99-73305	Y-12, A5 TYPICAL	17.00	11.7	0	0.69
1.b. 2.0014	UN 99-74151	Y-12, A5 TYPICAL	FAILURE TO START		1	
1.b. 2.0015	UN 99-96723	Y-12, A4 TYPICAL	20.73	20.5	8	0.99
1.b. 2.0017	AC 99-26752	A5 TYPICAL	21.25	10.4	0	0.49
1.b. 2.0018	AC 99-26755	A5 TYPICAL	14.25	6.1	2	0.43

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**POWER TEST 1050 KW
 $\Delta P_{20} = -35\text{PSI}$
(HELIUM OVER PRESSURE)**

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SCREENING TEST

J. C. Guzek

SCREENING TEST CONSIDERATIONS

*ASSESSMENTS OF PHASES III AND IV ELEMENTS INVOLVES IN PART SUBJECTING THESE ELEMENTS TO ELECTRICAL CORROSION TEST CONDITIONS WHICH BEST AFFORDS A REALISTIC APPRAISAL TO BE MADE OF FUEL ELEMENT PROCESS IMPROVEMENTS.

*IMPORTANT OBJECTIVES OF THE SCREENING TEST ARE THREE FOLD:

1. THE CONDITIONS ACHIEVED IN THIS ELECTRICAL TEST TO BE COMPARABLE TO MAXIMUM NOMINAL REACTOR CONDITIONS PARTICULARLY IN THE REGIONS OF MID BAND CORROSION AND AT THE HOT END OF THE ELEMENT.
2. SUCH A TEST SHOULD ALSO PROVIDE SOME MEASURE OF DETERMINING THE ENDURANCE CAPABILITY OF THE ELEMENT IN A REACTOR TEST.
3. SIMILARITY OF REACTOR BORE DAMAGE

* ASSUMING BORE TO EXTERNAL PRESSURE DIFFERENTIAL (ΔP) IS IMPORTANT FROM THE STANDPOINT OF ENHANCING PINHOLING WHICH IN TURN INDUCES SURFACE CORROSION. THEREFORE SET ELECTRICAL TEST ΔP AT THE AXIAL STATION OF MID BAND CORROSION TO THE MAXIMUM VALUE ATTAINED IN THE REACTOR (APPROXIMATELY STATION 20 INCHES).

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SCREENING TEST CONSIDERATIONS (CONTINUED)

*ASSUMING MASS FLOW IS AN IMPORTANT FACTOR SET HYDROGEN MASS FLOW EQUAL TO THE MAXIMUM NOMINAL VALUE ATTAINED IN THE REACTOR (1.2 POWER FACTOR REACTOR REGION).

*ELECTRICAL TESTING UNDER CONDITIONS OF ΔP MOST OFTEN IS TERMINATED WHEN THE ELEMENT PINHOLES WHICH PRECLUDES ATTAINING COMPARABLE REACTOR LIFE AS SUCH A SECONDARY TEST IS NECESSARY BUT WITH HELIUM OVERPRESSURE FOR THE PURPOSE OF ESTIMATING REACTOR LIFE TIME.

* MOVEOVER, IN EACH CASE AN ADDITIONAL TEST MUST BE PERFORMED AT RESPECTIVE INTERMEDIATE TIMES TO DEFINE THE CHARACTERISTIC CURVE OF WEIGHT LOSS VERSUS TIME CONSEQUENTLY SCREENING CONSISTS OF FOUR SPECIFIC TESTS.

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EFFECT OF ELEMENT POROSITY ON CORE STATION 20 PRESSURES FOR NRX/EST EOL

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COMPARISON OF COOLANT VELOCITY AND PRESSURE IN IMB TEST CONDITION WITH NRX REACTOR CONDITION

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NRX/EST RADIAL PRESSURE DIFFERENCE DISTRIBUTION CALCULATED AT STATION 20 INCHES

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COMPARISON OF AXIAL POWER DISTRIBUTION CORROSION TEST WITH NRX REACTOR

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ENVIRONMENTAL COMPARISONS BETWEEN REACTOR AND ELECTRICAL TESTS

	REACTOR			ELECTRICAL TEST	
	<u>℄</u>	<u>MID RADIUS</u>	<u>PERIPHERY</u>	<u>IMB</u>	<u>PHASE III SCREENING TEST</u>
POWER FACTOR	1.2	0.955	1.1	1.04	1.2
AVERAGE MAXIMUM TEMP - STA 20 - °R	2760	2679	2732	2800	2800
FLUID BORE VELOCITY STA 20 fps	780	668	650	800	920
MASS FLOW - LB/SEC	0.00266	0.00212	0.00244 - 0.00177	0.00233	0.00266
SCFM	(577)	(455)		(500)	(577)
MAXIMUM WEB TEMP DIFFERENCE - °R					
EXTERNAL	270	216	280	220	254
INTERNAL	150	119	150	90	104
ELEMENT RADIAL ΔP					
OUTSIDE WEB (STA 20 - 30)	25	-15	+6 to -30	-27	+30
MAXIMUM RADIAL ΔP					
INTERNAL ELEMENT (STA 20 - 30)	0	10	50*	0	0
ELECTRICAL POWER - KW				760	877

*MAXIMUM ACROSS ELEMENT MAX BORE TO BORE IS 15 PSI

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ELECTRICAL SCREENING TEST

<u>SURFACE TEMP - °R LAST SIGHT PORT</u>	<u>POWER-KW</u>	<u>H₂ FLOW SCFM</u>	<u>ΔP₂₀ PSI</u>	<u>RUN TIME</u>
4650 $\pm$ 90	900 $\pm$ 25	592 $\pm$ 15	+30	ttf OR 60 MIN WHICHEVER IS LESS
			-1/2 TO -3 H _e INLET OVERPRES- SURE	ttf OR 60 MIN WHICHEVER IS LESS
			+30	2/3 ttf OR 40 MIN WHICHEVER IS LESS
			-1/2 TO -3 H _e INLET OVERPRES- SURE	2/3 ttf OR 40 MIN WHICHEVER IS LESS

LOGIC - REACTOR POWER AT POWER FACTOR OF 1.2 = 877 (875 NOMINAL) AND IS TAKEN AS MINIMUM
 POWER TO BE RUN. HENCE WITH A $\pm$ 25 KW TOLERANCE THE MEAN WOULD BE 900 AND MAY BE 925.

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COMPARISON OF VOLUMETRIC & CYLINDRICAL SURFACE CORROSION MODES

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NRX-A6 OPERATING REACTIVITY LOSS BASED ON A SEMI-QUANTITATIVE ADJUSTMENT OF REACTOR DATA BY ELECTRICAL TEST DATA.

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DESCRIPTION OF CORROSION TEST CONDITIONS
PHOEBUS 1B FUEL ELEMENTS

	TEMP-°R	P-KW	FLOW-SCFM	ΔP_{20} -PSI	TEST-TIME
1. A6 ELEMENT DEVELOPMENT SCREENING TEST	4650 ± 90	900 ± 25	592 ± 15	30*	FAILURE & .75 TTF
2. PHOEBUS-1B REACTOR SCREENING TEST	4850 ± 90	1065 ± 25	$673 \pm 15^*$	0	FAILURE & .66 TTF .33 TTF
3. LASL 1B ELEMENT CORROSION TEST	4850 ± 90	1010 ± 25	654 ± 15	-1/2 TO -3 H_e OVERPRESSURE	TTF, 40 & 20 MIN

CORROSION TESTS 2 & 3 PRECEDED BY 2-MINUTE 3500°R BLOWDOWN AND TESTED WITH 750 PSIA CONTROLLED ELEMENT EXIT PRESSURE

* BASED ON MAXIMUM PHOEBUS 1B ELEMENT FLOW (1.093 P.F. CHANNEL)

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POST-TEST DESTRUCTIVE ANALYSIS

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CRACK PROFILE OF BATCH 8604, CHANNEL 5

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EFFECT OF NUMBER OF NbC CRACKS PER INCH UPON
INCREMENTAL LEAK RATE PER MINUTE OF CORROSION TEST TIME

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Not Molybdenum Coated

Station

10 - 15

15 - 20

20 - 25

25 - 30

TD-332

(a)

Molybdenum Coated

Station

10 - 15

15 - 20

20 - 25

25 - 30

(b)

Comparison of Standard and Molybdenum Overcoated Elements in the Mid-Band Region

a. (Not Molybdenum Coated-99-76141, 7603, $\Delta P = 45$, 83.2 Minutes)

b. (Molybdenum Coated - 99-76089, 7603/H15, $\Delta P = 40$, 75 Minutes)

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Laboratory

Station

10 - 15

TD-333

15 - 20

(a)

20 - 25

25 - 30

30 - 35

35 - 40

40 - 45

45 - 50

Increased Ring Corrosion Beyond Overcoat Range
(S/N 99-76425, 8604/H16, $\Delta P = +35$, 73.4 Minutes)

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PHASE II-1-B CYCLIC TESTING WEIGHT LOSS AS A
FUNCTION OF THE NUMBER OF CYCLES

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TYPICAL PRECORROSION TEST ER PROFILES OF PHASE I-2B (POWER AND FLOW;
BATCH 8994W) FUEL ELEMENTS

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CRACK DENSITY FOR RESISTANCE

TYPES I, II, AND III (PHASE II-1B, POWER & FLOW, BATCH 8994W)

ER TYPE	CHANNEL 8, AVERAGE NO. CRACKS/INCH									
	5	10	15	20	25	30	35	40	45	50
I	44	25	30	24	29	27	31	28	25	21
II	38	25	17	15	16	19	20	19	16	15
III	33	17	8	7	8	9	10	9	12	11

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PINHOLING PERFORMANCE OF PHASE II-1B
(POWER & FLOW) FUEL ELEMENTS

POWER (KW)	TOTAL PINHOLES/NO. OF ELEMENTS		
	TYPE I 24-30 CRACKS/ INCH	TYPE II 15-20 CRACKS/ INCH	TYPE III 7-10 CRACKS/ INCH
760	1/6	2/7 Excludes 1 F/E with severe SC (35 PH's)	14/2
905	0/1	11/4 Includes 1 F/E with 9 PH's where the F/E was bowed	30/2
1050	0/0	10/2	74/4

PEAK MID-BAND CORROSION RATES FOR PHASE II-1B
 (POWER & FLOW) CORROSION TESTS

ER TYPE	P (INLET)	$\Delta W/5''/10 \text{ MIN.}$				
		760 KW			905 KW	1050 KW
		48"	40"	36"	48"	48"
I 24-30 CRACKS/ INCH	-1/2		0.33	-	-	-
	20-30	0.26	-	0.23	0.24	-
	80-100	0.33	0.50	0.40	0.36	-
II 15-20 CRACKS/ INCH	-1/2	0.33			-	-
	20-30	-			0.43	0.43
	80-100	-			0.43	-
III 7-10 CRACKS/ INCH	-1/2	-			-	-
	20-30	-			0.43	0.43
	80-100	0.33			-	0.43

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PINHOLING BEHAVIOR OF PHASE II - 1B (POWER AND FLOW, BATCH 8994W)
FUEL ELEMENTS (NOTE: O PINHOLES 15 ELEMENTS, ER TYPES I AND II)

S/N	TEST NO.	TIME	Surface Corrosion ^(a)	P	KW	ER ^(b) TYPE	LENGTH	13-16	16-19	19-22	22-25	25-28	28-31	31-34	34-37	37-40	40-43	43-46	46-49	49-50	TOTAL
99-76294	2089	24.0	M 16-49	+37	1050	III	48		16	3	3	3		3	14	8	6			I	56
99-75860	2082	15.0	STREAK 26-49	+48	1050	III	48			2	1										3
76309	2065	12.2	L20-30 M30-49	+100	1040 1050	III	48				1	1		2	3	4	2				13
76255	2084	15.0	VL25-42 L42-49	+100	1046 1050	III	48			1	2										3
76042	2078	21.3	VL 33-49	+94	1030 1045	III	48		1	4											5
76062	2092	30.0	L27-42 M42-49	+30	905	III	48		4	3	10				1	2					20
76266	2085	8.3	L30-39 M39-49	+99	905	III	48							2	8		3				13
75879	2073	16.5	L38-49	+100	905 908	II	48			1							9 BOWED				10
76260	2077	12.2	NONE	+100	905 901	II	48			1											1
76490	2071	75.1	NONE	-6	760 760	III	44		2	2			1	1	3	1		8			18
76285	2080	45.0	NONE	+27	760	I	48		1	1											2
76404	2066	50.3	L35-40 M40-49	+80	760	II	40								2	14	18	1			35
76484	2068	14.8	L35-40 M40-50	+84	760	III	44					1	1			1					3
76253	2075	60.0	L18-38 M38-45 H45-49	+22	758 757	II	48	1	3		2									I	6*

ALL ELEMENTS - 99

*(a) VL = VERY LIGHT L = LIGHT M = MODERATE H = HEAVY

*(b) I, SMOOTH RESISTANCE PROFILE; II, INTERMEDIATE; III, DETAILED RESISTANCE PROFILE.

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FUEL DEVELOPMENT

INTRODUCTION

W. R. Ellis

FUEL DEVELOPMENT

1. COATING IMPROVEMENT

A. REDUCE CORROSION BEHIND CRACKS

10/15-1/1

MOLY OVERCOATING
LOWER COATING TEMPERATURE

B. INCREASE COATING ADHERENCE

10/20-12/15

COATING TEMPERATURE CHANGES

LOWER TEMPERATURE
CHANGING TEMPERATURE
REVERSE TEMPERATURE

STUDY COATING CHEMISTRY

METHANE ADDITION
SALT FLOW
GAS MIX
 NbBr_5

C. IMPROVED EXTERNAL COATING

12/1-1/1

2. TUBE LINER

11/15

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FUEL DEVELOPMENT

3. MATRIX IMPROVEMENT

A. THERMAL COEFFICIENT OF EXPANSION

HIGH EXPANSION FLOUR

B. REDUCE PERMEABILITY

REVISE MIXING AND EXTRUSION
IMPREGNATION
PyC ON BORES AND OUTSIDE
EXTRUDE TO SIZE

C. BETTER COATING ADHERENCE

MORE COMPLETE LEACH
CARBIDE ADDITIONS
PyC UNDERCOAT ON BORES
EXTRUDE BORES TO SIZE

D. INCREASE MATRIX CORROSION RESISTANCE

SILICON ADDITIONS
CARBIDE ADDITIONS

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RESULT OF MATRIX PERMEABILITY REDUCTION PROGRAM

J. D. Holmgren

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NRX A-6 TOTAL BODY LEAKAGE
CODE 9 F/E - GA FUEL

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SUMMARY OF BODY LEAK DATA
GA FUEL

	<u>Loading</u> <u>mg/cc</u>	<u>Range</u> <u>cc/min.</u>	<u>Avg.</u> <u>cc/min.</u>	<u>No. of</u> <u>Samples</u>
NRX				
WAFF NRX A-5 - As Leached	432	176-912	404	58
WAFF NRX A-5 As bore coated	432	51-187	108	62
WAFF NRX A-6 As Leached	432	130-650	337	55
WAFF NRX A-6 As bore coated	432	0-540	151	267
Y-12 NRX A-6 - As Leached *	432	7-136	49	179
PHOEBUS**				
LASL Phoebus 1A - As Leached	-	0-214	40	16
Y-12 Phoebus 1A - As Leached	-	0-280	34	10
Y-12 Phoebus 1B - As Leached	-	0-250	84	17
LASL Phoebus IIA - As Leached***	-	0-256	83	20

* Y-12 Data

** LASL Data

*** High Void Fraction Fuel Elements - Hole Diameter 0.115 in.

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PROCESS VARIABLES BEING INVESTIGATED IN THE FUEL ELEMENT MATRIX PERMEABILITY PROGRAM

I. RAW MATERIALS AND COMPOSITION

1. Thermax
2. Flour
3. Binder Content

II. MIXING AND EXTRUSION

1. Binder Temperature
2. Precompact Technique
3. Green Mix Storage
4. Cylinder Size
5. Die
6. Extrusion Rate
7. Extrusion Cycles

III. THERMAL TREATMENT

1. Cure Cycle
2. Cure Fixturing
3. Bake Cycle
4. Graphitize Cycle

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**SIGNIFICANT MATRIX DEVELOPMENT RESULTS
AS-MACHINED CODE 9 FUEL ELEMENTS - GA FUEL**

	Total Body Leak cc/min. air at 10 psig		No. of Samples
	<u>Range</u>	<u>Avg.</u>	
1. Y12 Baked & Graphitized of WAFF Extruded and Cured	280-700	402	14
2. WAFF Baked & Graphitized of Y12 Extruded and Cured	74-105	89	5
3. Y12 Baked & Graphitized of Y12 Extruded and Cured		122*	30
4. WAFF Duplicate of LASL Process			
Stainless Thermax - 2 pass	40-140	87	8
Stainless Thermax - 3 pass	38- 58	47	4
Regular Thermax - 2 pass	5-115	70	8
Regular Thermax - 3 pass	16- 29	23	5
5. WAFF Standard A-6 Process with Y12 Die			
Regular Thermax	83-125	105	4
Stainless Thermax	44- 93	65	4
6. WAFF Standard A-6 Process with Y12 Cure Cycle & Stainless Thermax	375-710	572	7
7. WAFF Standard A-6 Process with Sealed Cure Fixture			
Regular Thermax	340-705	496	4
Stainless Thermax	660-860	770	3
8. WAFF Standard A-6 Process with LASL Compacting			
Regular Thermax	205-780	425	4
Stainless Thermax	525-670	559	3

* As-Leached measured at Y12

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AS-MACHINED TOTAL BODY LEAKAGE
TASK III-22 - CODE 9 FUEL ELEMENTS, GA FUEL

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CONCLUSIONS

Major Variables Affecting Matrix Permeability

1. Die
2. Number of Extrusion Passes
3. Thermax and Flour

Minor Variables Affecting Matrix Permeability

1. Bake Cycle
2. Graphitizing Cycle

Variables to be Examined

1. Cure Cycle and Fixturing
2. Extrusion Rate

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PHASES III AND IV FUEL DEVELOPMENT

A. Boltax

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STANDARD NERVA MATRIX, AFTER
20 MINUTES HYDROGEN CORROSION
TEST AT 1500°C, 500 PSI, 100 SCFM.

MATRIX MADE WITH SILICONE GLYCOL
COPOLYMER ADDITIVE AFTER 20
MINUTE HYDROGEN CORROSION TEST
AT 1500 °C, 500 PSI, 100 SCFM

**COMPARISON OF HYDROGEN CORROSION BEHAVIOR
OF UNCOATED GRAPHITE SPECIMENS WITH AND
WITHOUT SILICONE GLYCOL ADDITIVE**

611404-58B

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C-250X

D-250X

EFFECTS OF COATING TEMPERATURE AND PROFILE ON NbC GRAIN SIZE

- A- STANDARD A-6 COATING, 8 HOURS 1900°C, 2.0 MILS AT 20 INCHES
- B- 24 HOUR COATING, 1675°C, 1.5 MILS AT 20 INCHES
- C- 17 HOUR COATING, 1500°C
- D- 9 HOUR COATING WITH CH₄, 1000°C,

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Y-12 RESULTS ON MATRIX AND COATING

F. Tench

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HOT-GAS TEST PERFORMANCE

ORIGINAL NbCl ₅ COATING RUN NO.	WT GAIN (g)	MOLY OVERCOAT WT GAIN (g)	NbBr ₅ OVERCOAT WT GAIN (g)	NO. OF ELEMENTS	HOT-GAS TEST DATA					
					TEMP (°C)	TIME (min)	TEST PRESS. (lbs/hr)	WEIGHT LOSS (g)	AVG (g/min)	
8956R	73	xx	xx	2	2400	15 - 30	140	8-17	0.56 - 0.57	0.57
8956R	73	2-6	xx	5	2400	30	140	13-17	0.43 - 0.59	0.50
MISC.	74	2-4	xx	5	2250	30	140	10-14	0.33 - 0.46	0.40
8956	73	xx	2.5	2	2250	30	140	5-5 1/2	0.17 - 0.18	0.18

HOT-GAS INCREMENTAL WT. LOSS FOR NbBr₅ OVERCOATED ELEMENTS

ELEMENT NO.	WT. LOSS (g)				
	0-10"	10-20"	20-30"	30-40"	40-50"
0-437-23412	0.4	1.2	1.4	0.4	2.1
0-437-22432	0.2	0.8	0.4	0.8	3.0

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Laboratory

HOT-GAS TEST PERFORMANCE NbC BORE COAT
PLUS MOLYBDENUM OVERCOAT

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NRXA-4 - WANL INTERPRETATION OF ELEMENTS

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NbC COATING PROFILE USING NbBr_5 AND HOT-GAS TEST PERFORMANCE

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HOT GAS TEST PERFORMANCE
NbC BORE COAT ONLY

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WHOLE BODY LEAK RATE -
 DRY AIR AT 10 PSIG

(UNLOADED CARBON ELEMENTS TESTED AS MACHINED-0.110-INCH HOLES)

	<u>NORMAL CYCLE</u>	<u>21 HOUR CURE</u>	<u>84 HOUR CURE</u>
NUMBER TESTED	6	19	10
AVERAGE (cc/min)	54	65	57
MAXIMUM (cc/min)	116	109	82
MINIMUM (cc/min)	10	31	31
	<u>NORMAL CYCLE OLD FLOUR</u>	<u>NORMAL CYCLE NEW FLOUR</u>	<u>NORMAL CYCLE NEW FLOUR SPECIAL BLEND</u>
NUMBER TESTED	6	18	10
AVERAGE (cc/min)	54	203	173
MAXIMUM (cc/min)	116	252	228
MINIMUM (cc/min)	10	160	139

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CONFIDENTIALWHOLE BODY LEAK RATE -
DRY AIR AT 10 PSIG

(CODE 9 ELEMENTS)

	<u>OLD FLOUR</u>	<u>NEW FLOUR</u>
NUMBER TESTED	179	26
AVERAGE (cc/min)	51	112
MAXIMUM (cc/min)	136	326
MINIMUM (cc/min)	7	51

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PHASE IV - DEVELOPMENT

- I. MATRIX IMPROVEMENT
 - 1. SUBSTITUTION OF GRAPHITE FOR THERMAX CARBON BLACK.
 - 2. BINDER MODIFICATIONS
 - 3. INCORPORATION OF Nb COATED GRAPHITE PARTICLES.

- II. HOT END MODIFICATION
 - 1. VAPOR DEPOSIT TaC ON THE ELEMENT HOT END FROM
40 - 52 INCHES.

- III. UC₂ BEAD MODIFICATION
 - 1. INCORPORATION OF Nb COATED UC₂ BEADS IN ELEMENT
MATRICES.

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WHOLE BODY LEAK RATE —
 DRY AIR 10 PSIG

(CODE 9 ELEMENT)

	<u>NORMAL CYCLE</u>	<u>PRESSURE CURED</u>	<u>IMPREGNATED AS 850° BAKE</u>
NUMBER TESTED	179	2	14
AVERAGE (cc/min)	51	34	46
MAXIMUM (cc/min)	136	34	133
MINIMUM (cc/min)	7	34	20
	<u>NORMAL CYCLE</u>	<u>IMPREGNATED AS GRAPHITIZED</u>	<u>IMPREGNATED AS LEACHED</u>
NUMBER TESTED	179	14	10
AVERAGE (cc/min)	51	22.	3
MAXIMUM (cc/min)	136	48	7
MINIMUM (cc/min)	7	7	0

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WHOLE BODY LEAK RATE —
DRY AIR AT 10 PSIG

(UNLOADED CARBON ELEMENTS TESTED AS MACHINED-0.099-INCH HOLES)

	<u>NORMAL CYCLE</u>	<u>21 HOUR CURE</u>	<u>84 HOUR CURE</u>
NUMBER TESTED		23	26
AVERAGE (cc/min)		29	19
MAXIMUM (cc/min)		58	44
MINIMUM (cc/min)		17	7

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SUMMARY OF HOT GAS TEST RESULTS

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1B Elements - 1B Test										
	1	2	3	4	5	6	7	8	9	10
445-21587	30 min. $\Delta W = 12.9$ Rate = 0.43									
69.0 NbC (2 mo)										
Incremental Weight Loss	0	0	0.1	0.5	0	0	0.5	2.2	3.3	6.3
445-21600	30 min. $\Delta W = 14.4$ Rate = 0.48									
68.0 NbC (2 mo)										
Incremental Weight Loss	0	0	0.1	0	0	0	0.9	1.7	4.5	7.1
445-21602	30 min. $\Delta W = 9.4$ Rate = 0.31									
69.4 NbC (2 mo)										
Incremental Weight Loss	0	0	0.3	0	0	0.1	0.3	1.3	2.6	4.8
Incremental Weight Loss										

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A4/A5 Elements - A6 Test										
	1	2	3	4	5	6	7	8	9	10
79-18009 (300-24993) 44.6 NbC F-145 (good) Incremental Weight Loss	30 min. $\Delta W = 9.6$ Rate = 0.32									
	0	0.4	0.3	2.3	1.9	0.4	0.1	0.5	1.4	2.2*
99-19936 (400-24995) 43.5 NbC C-167 (poor) Incremental Weight Loss	30 min. $\Delta W = 12.7$ Rate = 0.42									
	0	0	0.9	5.6	3.1	0.9	0.2	0.2	0.7	1.2
Incremental Weight Loss										
Incremental Weight Loss										

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IB Elements - IB Test (Life)										
	1	2	3	4	5	6	7	8	9	10
467-21206	42.5 min. $\Delta W = 17.1$ Rate = 0.40									
71.0 NbC (2 Mo)	$\frac{+11.25}{53.75}$ $\Delta W = 25.9$ (corr.) Rate = 0.48									
Incremental Weight Loss	0	0	1.1	1.4	0.2	0	1.2	2.1	5.2	14.6
467-21210	63 min. $\Delta W = 25.0$ Rate = 0.40									
70.0 NbC (2 Mo)										
Incremental Weight Loss	0	0.5	4.8	3.9	0.4	0	0.4	2.1	4.6	8.5
467-21203	71 min. $\Delta W = 29.5$ Rate = 0.41									
73.9 NbC (2 Mo)										
Incremental Weight Loss	0.1	0.9	5.0	3.6	0	0	1.0	2.2	6.3	10.3
Incremental Weight Loss										

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2A Elements - 2A 4100 Special										
	1	2	3	4	5	6	7	8	9	10
295-41580 84.9 NbC (3 mo) Incremental Weight Loss	20 + 1/2 min. $\Delta W = 5.3 + 0.2 = 5.5$ Rate = 0.27									
	1.1	0	0.2	0.8	1.4	0.8	0.2	0	0.8	0
295-41576 85.1 NbC (3 mo) Incremental Weight Loss	20 + 20 + 1/2 min. $\Delta W = 5.2 + 9.4 + 1.4 = 16.0$ Rate = 0.40 (parted 51" 3rd cycle)									
	1.1	0	0.3	1.1	3.2	4.7	2.4	1.5	1.2	0.5
295-41577 85.5 NbC (3 mo) Incremental Weight Loss	20 + 20 + 1/2 min. $\Delta W = 4.3 + 8.3 + 0.5 = 13.1$ Rate = 0.33 (parted 51" 3rd cycle)									
	0.8	0	0.1	0.8	2.4	3.6	2.2	1.7	1.5	0.6
Incremental Weight Loss										

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A4/A5 Elements - Modified IB Test (Exit Press. = 550 psi)										
	1	2	3	4	5	6	7	8	9	10
99-28505 (W) (A5) (400-24999) 60 NbC C-272 (good) Incremental Weight Loss	15 + 6.75 min. $\Delta W = 8.2 + 12.1 = 20.3$ (-3.0 HE = 17.3) (21.75) parted 18 1/2" Rate = 0.78									
	0	0	1.1	7.0	2.1	1.5	1.2	1.4	1.1	1.9*
99-28774 (W) (A5) (400-24991) 56.5 NbC C-273 (poor) Incremental Weight Loss	15 + 10 min. $\Delta W = 7.8 + 17.3 = 25.1$ (-2.0 HE = 23.1) (O.P., PH 19-20) Rate = 0.92									
	0	0	0.8	8.0	4.3	2.0	1.6	1.7	2.1	2.7
99-97164 Y-12 (A4) (400-24973) 53.4 NbC 57 (10B) (good) Incremental Weight Loss	15 + 10.75 min. $\Delta W = 8.4 + 10.6 = 19.0$ (-0.5 HE = 18.5) (O.P., PH @ HE) Rate = 0.72									
	0	0	3.0	2.7	1.5	0.7	0.7	1.6	3.4	5.1
99-97804 Y-12 (A4) (400-24980) 45.0 NbC 69 (IA) (poor) Incremental Weight Loss	15 + 7.5 $\Delta W = 12.6 + 15.7 = 28.3$ (-3.0 HE = 25.3) (no. 7 too high) Rate = 1.12									
	0	1.9	9.7	6.7	2.1	0.4	0.2	0.6	1.2	2.5

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1B Elements - 1B Test										
	1	2	3	4	5	6	7	8	9	10
445-21607 68.3 NbC (2 mo) Incremental Weight Loss	35 min. $\Delta W = 16.9$ Rate = 0.48 (O.P., PH @ H.E.)									
	0	0	0.6	0.5	0.1	0.1	0.8	1.8	4.5	8.4*
445-21589 68.4 NbC (2 mo) Incremental Weight Loss	57 min. $\Delta W = 23.2$ Rate = 0.41									
	0	0.2	2.1	1.6	0.2	0.1	1.3	2.1	5.4	10.3
445-21610 69.8 NbC (2 mo) Incremental Weight Loss	60 min. $\Delta W = 20.5$ Rate = 0.34									
	0.3	0	1.7	1.6	0.4	0.2	1.1	1.9	4.7	8.4
Incremental Weight Loss										

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1B Elements - A6 Test										
	1	2	3	4	5	6	7	8	9	10
445-21626	30 min. $\Delta W = 7.9$ Rate = 0.26									
69.3 NbC (2 mo) Incremental Weight Loss	0.4	0	0.2	0.2	0	0	0.2	0.7	2.2	4.1
445-21603	30 min. $\Delta W = 10.0$ Rate = 0.33									
68.5 NbC (2 mo) Incremental Weight Loss	1.9	1.3	0.4	0	0	0	0	0.7	1.8	3.9
445-21619	30 min. $\Delta W = 8.2$ Rate = 0.27									
68.2 NbC (2 mo) Incremental Weight Loss	0	0	0.1	0	0	0.3	0	1.0	2.7	4.1
Incremental Weight Loss										

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A4/A5 Elements - A6 Test										
	1	2	3	4	5	6	7	8	9	10
99-28623 (A5) (400-24998) 69.5 NbC C-271 (good) Incremental Weight Loss	15 + 15 min. $\Delta W = 6.3 + 5.9 = 12.2$ Rate = 0.41									
	0	0	0	1.3	2.3	1.6	0.9	1.0	2.1	3.1
99-28575 (A5) (400-24986) 56.0 NbC C-270 (poor) Incremental Weight Loss	15 + 15 min. $\Delta W = 5.1 + 9.4 = 14.5$ Rate = 0.48									
	0	0	0	2.2	3.4	2.0	1.9	2.0	1.3	1.1
99-74596 (A5) (400-24983) 66.6 NbC Y-12 (A5) 9533W (good) Incremental Weight Loss	15 + 15 min. $\Delta W = 4.6 + 9.9 = 14.5$ (-1.5 HE = 13.0) Rate = 0.43									
	0	0	0	1.5	2.1	1.1	1.4	1.7	2.2	2.9
99-97814 (A4) (400-24985) 46.1 NbC Y-12 (A4) 69 (IA) (poor) Incremental Weight Loss	15 + 15 min. $\Delta W = 8.2 + 13.7 = 21.9$ (-1.5 HE = 20.4) Rate = 0.68									
	0	0	0.4	7.4	4.9	1.5	0.7	0.5	2.1	3.0

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Test Conditions				
Type	Power	H ₂ lbs/hr	Exit psi	Orifices
Standard				
RPT-4810R	0.75 MW	140	550	Yes
IBRPT-4500	1.01	205	750	No
2ARPT-4500	1.25	250	625	No
Special				
A6-4500	0.69	140	550	No
2A-4100	0.91	250	625	No

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Summary - I										Slide 1
Test Type	Element Type	Wt. Loss	Test Time	Loss Rate	Incremental Loss					Number Elements
					0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	
4810	IB (NbC)	12.9	30	0.43	-	-	-	-	-	78.
4810	IB (NbC)	11.9	30	0.40	-	3.9	1.5	1.3	5.1	10
IB	IB (NbC)	18.1	30	0.60	1.8	10.4	2.5	1.0	3.0	5
IB	IB (Mo)	7.9	30	0.26	-	0.6	0.4	1.4	5.4	6
IB	IB (Mo)	8.7	15 + 15	0.29		0.9	1.0	2.2	5.2	2
IB	IB (Mo)	10.2	10 + 20	0.34	-	1.0	1.3	1.6	5.1	2

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Mo - Coated A4/A5 Elements - IB Test (Life)

	1	2	3	4	5	6	7	8	9	10
99-25904 (A5) (400-24978) (3.50 Mo) C-291 (good) Incremental Weight Loss	<u>86 min.</u> - Element parted suddenly at 17" - most of element lost.									
99-28546 (A5) (400-24996) 55 NbC (3.57 Mo) C-273 (poor) Incremental Weight Loss	0	0	3.9	3.9	1.3	0.4	1.1	1.4	3.9	6.6
99-98386 Y-12(A4) (400-24974) 50.5 NbC (2.76 Mo) 84(6B) (good) Incremental Weight Loss	0.2	0.6	1.8	1.0	0	0	0	1.5	4.7	9.3
99-97789 Y-12(A4) (400-24981) 46.8 NbC (2.96 Mo) 69 (IA) (poor) Incremental Weight Loss	0	3.8	2.5	1.2	0	0.4	0	0	0	1.2

Reactor Reactor Test or Experiment	Power MW	Duration Min.	Fuel Channel Flow Data								Station 20 Fuel Channel Information														
			Exit Temp °R	Exit Press psia	Press Drop psid	Total Flow lb/sec	Channel Avg Dia. In.	Orifice Size, In			Power Density Btu/in ³ -sec			Flow Rates lb/sec, x10 ³			Reynolds No, x10 ⁻⁴			Channel Pressure psia			Temperatures, °R		
								Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Bulk Gas	Channel Wall	Max Material
Phoebus-1A	1090	11	4440	550	102	62	.095	.070	.038	.030	44 (1.16)	38 (1.0)	30 (.79)	2.4	2.1	1.7	2.7	2.3	1.8	630	616	600	1980	2780	2900
NRX-A4	1100	30	4300	570	125	67	.095	.070	.035	.026	54 (1.23)	45 (1.0)	34 (.76)	2.7	2.2	1.7	3.3	2.7	2.0	660	630	590	1750	2550	2650
NRX-A5	1100	30	4300	570	125	67	.095	.070	.034	.024	54 (1.23)	45 (1.0)	32 (.70)	2.7	2.2	1.7	3.2	2.6	1.8	680	650	600	1860	2600	2700
Phoebus-1B	1500	30	4500	750	127	82	.097	.070	.042	.030	75 (1.10)	68 (1.0)	48 (.71)	3.2	2.9	2.1	3.5	3.2	2.2	860	845	820	1990	2790	2960
Phoebus-1B (Spec. 110-mil)	----	30	4500	750	127	--	.0106	.070	.039	.030	102 (1.13)	90 (1.0)	70.5 (.78)	3.6	3.3	2.6	3.5	3.2	2.2	855	835	810	1990	2900	3060
Phoebus-1B	1000	30	4500	625	71	52	.097	.070	.042	.030	43 (1.13)	38 (1.0)	30 (.78)	2.1	1.9	1.5	2.3	2.0	1.6	450	440	425	1270	1850	1960
Phoebus-2A	5000	30	4570	625	150	280	.106	.070	.046	.031	97 (1.07)	91 (1.0)	69 (.76)	3.9	3.6	2.7	3.9	3.6	2.7	750	730	690	1950	2810	3000
RPT-4810 (100 mil)	----	30	4770 ⁴ 4820	562	138	.039 (140) ¹	.096	.048 ² ---	#	---	39.8	39.8	39.8	2.5 ---	#	---	2.6 ---	#	---	656 ---	#	---	2260 2690	2830 3265	2940 3390
1B-RPT-4500 (100 mil)	----	30	4430 4600	762	119	.057 (205)	.096	None			50.2			2.98 ----	#	---				853 ---	#	---	2200 2330	2840 2890	2960 3060
RPT-4810 (110 mil)	----	30	4830 4700	562	110	.039 (140)	.105	.048 ---	#	---	43.4 ----	#	43.4	2.6 ---	#	---	2.4 ---	#	---	630 ---	#	---	2350 2740	2810 3360	3170 3480
2A-RPT-4500	----	30	4660 4440	662	128	.069 (250)	.105	None			65.9	#	65.9	3.63 ---	#	---				760 ---	#	---	2275 2320	2850 2950	3020 3150

1. (140) refers to 140 lbs H₂/hr/fuel element.
2. .048 --- .032 refers to 0.048 mil orifices in inner seven holes and 0.032 mil orifices in outer 12 holes.
3. (.79) refers to power factor based on average orificed channel having a power factor of 1.0.
4. The two temperatures refer to exit temperature of inner and outer bores respectively.

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1B Elements - 2A Test (Life)										
	1	2	3	4	5	6	7	8	9	10
467-21218	30.5 min. $\Delta W =$ Rate = (temp. @ 16" rising - element broke at 11" on cooldown — element lost)									
Incremental Weight Loss										
467-21221	32 min. $\Delta W = 16.5$ Rate = 0.51									
70.3 NbC (2 Mo)										
Incremental Weight Loss	0	0	2.1	0.2	0	0	0.2	1.5	4.8	7.4
467-21241	20.5 min. $\Delta W = 12.2$ Rate = 0.59									
73.2 NbC (2 Mo)										
Incremental Weight Loss	0	0	0.4	0	0	0	0	1.5	3.7	6.1
Incremental Weight Loss										

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Summary - II										Slide 1
Test Type	Element Type	Wt. Loss	Test Time	Loss Rate	Incremental Loss					Number Elements
					0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	
A6	IB (Mo)	8.7	30	0.29	1.2	0.3	0.1	0.9	6.3	3
A6	IB (Mo)	14.8	60	0.24	0.4	1.2	0.3	1.9	10.1	3
IB	IB (Mo)	12.2	30	0.41	0	0.3	0.1	2.3	9.5	3
IB	IB (Mo)	20.5	60	0.34	0.3	3.3	0.6	3.0	13.1	1
IB	IB (Mo)	25.0	63	0.40	0.5	8.7	0.4	2.5	13.1	1
IB	IB (Mo)	29.5	71	0.41	1.0	8.6	0	3.2	16.6	1

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Summary - I										Slide 2
Test Type	Element Type	Wt. Loss	Test Time	Loss Rate	Incremental Loss					Number Elements
					0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	
IB	IB (Mo)	10.2	10 + 20	0.34	-	1.0	1.3	1.6	5.1	2
IB	IB (Mo)	16.3	20 + 20	0.41	-	1.4	1.0	2.9	9.1	2
IB	IB (Mo)	22.6	90	0.25	0.3	3.4	1.0	4.7	13.2	1
4810	2A (NbC)	14.3	30	0.48	2.8	6.2	1.1	0.9	3.4	~75
2A	2A (Mo)	12.2	30	0.41	-	-	-	-	-	10

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A4/A5 Elements - 4810 Test										
	1	2	3	4	5	6	7	8	9	10
69-21318 (400-24987) 49 NbC F-151 (good) Incremental Weight Loss	30 min. $\Delta W = 13.9$ Rate = 0.46									
	0	0	0	2.6	1.3	0.1	0.5	1.5	3.2	4.6
99-20102 (400-24988) 43.8 NbC C-167 (poor) Incremental Weight Loss	16 min. $\Delta W = 7.8$ Rate = 0.49 (O.P., PH @ 49")									
	0.3	0.4	1.2	2.2	1.0	0	0	0	0.9	1.8
Incremental Weight Loss										
Incremental Weight Loss										

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1B Elements - A6 Test										
	1	2	3	4	5	6	7	8	9	10
445-21623	60 min. $\Delta W = 16.2$ Rate = 0.27									
68.9 NbC (2 mo)										
Incremental Weight Loss	1.1	0.2	0.6	1.0	0.1	0	0.4	1.4	3.9	6.9
445-21620	60 min. $\Delta W = 13.7$ Rate = 0.23									
69.7 NbC (2 mo)										
Incremental Weight Loss	0	0	0.4	0.2	0	0	0.7	1.1	3.9	5.4
445-21595	60 min. $\Delta W = 14.5$ Rate = 0.24									
68.2 NbC (2 mo)										
Incremental Weight Loss	0	0	0.1	1.3	0.8	0	0.8	1.5	3.6	6.5
Incremental Weight Loss										

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1B Elements - 2A Test										
	1	2	3	4	5	6	7	8	9	10
445-21604 69.1 NbC (2 mo) Incremental Weight Loss	20.75 min. $\Delta W = 11.4$ Rate = 0.55 (O.P., PH @ HE)									
	0	0.4	0.1	0.4	0.1	0.3	0.3	1.9	2.8	5.1
445-21593 67.1 NbC (2 mo) Incremental Weight Loss	26.5 min. $\Delta W = 14.4$ Rate = 0.54									
	0	0.4	1.1	0	0	0	0.3	1.9	3.3	7.0
445-21615 68.5 NbC (2 mo) Incremental Weight Loss	30 min. $\Delta W = 15.5$ Rate = 0.55									
	0	0.1	1.1	0.7	0.3	0.1	0.8	1.9	4.1	6.5
445-21627 68.9 NbC (2 mo) Incremental Weight Loss	30 min. $\Delta W = 13.8$ Rate = 0.46									
	0	0.9	0.7	0	0	0	1.0	2.0	3.7	5.5

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2A Elements - 2A Test										
	1	2	3	4	5	6	7	8	9	10
295-41575 (Life) 84.8 NbC (3 mo) Incremental Weight Loss	62.5 min. $\Delta W = 22.9$ Rate = 0.37 (O.P., PH @ HE)									
	1.3	0.7	3.8	3.1	1.4	0.6	1.0	1.3	3.4	6.5
295-41572 Incremental Weight Loss	30 min. $\Delta W = 15.0$ Rate = 0.50									
295-41561 Incremental Weight Loss	30 min. $\Delta W = 17.0$ Rate = 0.57									
Incremental Weight Loss										

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2A Elements - 1B Test

	1	2	3	4	5	6	7	8	9	10
295-41568	30 min. $\Delta W = 13.3$ Rate = 0.44									
Incremental Weight Loss										
295-41562	30 min. $\Delta W = 14.3$ Rate = 0.48									
Incremental Weight Loss										
295-41578 85.7 NbC (3 mo)	30 min. $\Delta W = 12.0$ Rate = 0.40									
Incremental Weight Loss	0.8	0	1.7	1.4	0.5	0.3	0.3	0.9	2.6	3.8
Incremental Weight Loss										

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Summary - II										Slide 2
Test Type	Element Type	Wt. Loss	Test Time	Loss Rate	Incremental Loss					Number Elements
					0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	
2A	IB (Mo)	14.6	30	0.49	0.5	1.3	0.2	2.9	9.9	2
2A	IB (Mo)	16.5	32	0.51	0	2.3	0	1.7	12.2	1
1B	2A (Mo)	13.2	30	0.44	-	-	-	-	-	3
2A	2A (Mo)	16.0	30	0.53	-	-	-	-	-	2
2A	2A (Mo)	22.9	62.5	0.37	2.0	6.9	2.0	2.3	9.9	1
2A (4100)	2A (Mo)	14.5	20 + 20	0.36	1.0	1.2	6.9	3.9	1.9	2

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LASL COATING DEVELOPMENT PROGRAM

M. G. Bowman

GRAPHITE DEVELOPMENTS - CARBIDE COMPOSITES

J. M. Taub

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EFFECT OF IRON CONTENT

85 W% NbC - 15 W% C

NO BINDER

2700 °C - 2000 PSI - 30 MIN

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250x
"AS GRAPHITIZED"
BRAZE TEMP. — 2620°C
TIME ————— 3'
PRESSURE — ~2000 psi
2 MIL Mo FOIL

250x
"FINISH MACHINED"
BRAZE TEMP. — 2620°C
TIME ————— 3'
PRESSURE — ~2000 psi
2 MIL Mo FOIL

BRAZED COMPARATIVE MICROSTRUCTURES OF
FUEL ELEMENTS IN THE AS GRAPHITIZED AND
FINISH MACHINED CONDITIONS.

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100x

250x

BRAZING CONDITIONS
TEMPERATURE — 2820°C
PRESSURE — 735 PSI
TIME — 3 MINUTES

MICROSTRUCTURE OF UNLOADED GRAPHITE
BRAZED TO UNLOADED GRAPHITE WITH 2 MIL
W FOIL.

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LASL SUMMARY

R. W. Spence

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Type of Test	Type of Elem.	No. of Samples	Time of Test (Min.)	Weight Loss Rate (Grams/Hour) 4500°R Exit Gas Temperature Mostly Ph-1B Elements (Y-12 Production, Mo-coated at LASL)											Total	Remarks
				0-5"	5-10"	10-15"	15-20"	20-25"	25-30"	30-35"	35-40"	40-45"	45-50"			
A-6 140 Lb/Hr 0.7 MW	1B	3	30	1.5	0.9	0.5	0.1	0	0.2	0.1	1.6	4.5	8.1	17.5	Loss in 0-10" region may be due to Mo loss	
A-6 140 Lb/Hr 0.7 MW	1B	3	60	0.4	0.1	0.4	0.8	0.3	0	0.6	1.3	3.8	6.3	14.0		
1B 205 Lb/Hr 1.0 MW	1B	4	30	0	0	0.6	0.5	0	0.1	1.2	3.4	7.2	12.7	25.7	Mid-band O. K.	
1B 205 Lb/Hr 1.0 MW	1B	2	57 and 60	0.2	0.1	2.0	1.7	0.3	0.2	1.3	2.1	5.2	9.6	22.7	Mid-band showing corrosion	
1B 205 Lb/Hr 1.0 MW	1B	2	63 and	0.1	0.7	4.4	3.4	0.2	0	0.6	2.0	4.9	8.4	24.7	Mid-band failure Life-times no more than ~ 60 minutes under these conditions.	
2A 250 Lb/Hr 1.25 MW	1B	6	20- 32	0	0.6	1.9	0.5	0.6	0.1	0.9	4.1	8.5	14.4	31.6	Most of increased rate at hot end - but one element failed at mid-band.	
2A 250 Lb/Hr 1.25 MW	2A	1	62.5	1.2	0.7	3.6	3.0	1.3	0.6	1.0	1.2	3.3	6.2	23.1	Single 2A element. Plenty of mid-band corrosion although test stopped for pinhole at hot end.	
2A 250 Lb/Hr 4100°R	2A	2	40 (20+20)	1.4	0	0.3	1.4	4.2	6.2	3.5	2.4	2.0	0.8	22.2	Samples run at 4100°R, exit gas. Note shift in axial corrosion and reduced weight loss at hot end.	
1B 205 Lb/Hr 1.0 MW	2A	1	30	1.6	0	3.4	2.8	1.0	0.6	0.6	1.8	5.1	7.6	24.0	This 2A element test to be compared with similar 1B element tests above.	

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TEST DATA ON CARBIDE COMPOSITE HOT ENDS
FOR FUEL ELEMENTS AND SUPPORT SYSTEMS

L. L. Lyon

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CORROSION TESTS OF UNCOATED COMPOSITE TIPS

140 LBS/HR., 4800°R, 550 PSIG H₂, 30 MINUTES

<u>SAMPLE</u>	<u>CARBON LOSS %</u>	<u>SHRINKAGE, INCHES</u>	
		<u>LENGTH</u>	<u>FLATS</u>
85 W/O NbC VARCUM	15%	-.002/1.3	-.002/.75
85 W/O NbC GRAPHITE	16%	-.002/1.4	-.002/.75
85 W/O NbC VARCUM	16%	-.035/1.4	-.002/.75
75 W/O NbC VARCUM	25%	-.004/1.4	-.004/.75
75 W/O NbC VARCUM	25%	+.004/1.4	-.005/.75

LOAD PROPERTIES OF LEACHED MATERIAL:

1000 LBS. ON FUEL ELEMENT FACE AT 2700°C RESULTS IN LARGE DEFORMATION AND EVENTUAL CRUSHING. 85 W/O MORE RESISTANT THAN 70 W/O.

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LASL FUEL ELEMENT TEST PROGRAM FOR
THE NEXT THREE TO FOUR MONTHS

D. P. MacMillan

REACTOR DESIGN EFFECTS ON FUEL PERFORMANCE

INTRODUCTION

H. S. McCreary

NRX-A6 DESIGN OBJECTIVE

- SIGNIFICANT FUEL LIFE IMPROVEMENT
- FEATURES INTO NERVA ENGINE

NRX-A6 DESIGN FEATURES

- INCREASED INTERSTITIAL PRESSURE
HOT END BUNDLING
- REDUCED RADIAL INFLOW
GRAFOIL WRAPPER
- HELIUM INJECTION
- INCREASE ORIFICE PRESSURE DROP
- FLATTEN POWER PROFILE

611407-7B

NRX-A6 DESIGN FEATURES

- ORIFICE SIZING
PREVENT PERIPHERAL BRIDGING
REDUCE ELEMENT ΔP
- ELEMENT SIZING
CENTRAL AND PERIPHERAL
FILLER STRIP

611407-6B

DESIGN FEATURES AND MECHANICAL IMPROVEMENTS

W. G. Brussalis

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HHT7 BUILD 4 TEST 2 AFT END CONFIGURATION

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PYROFOIL
.010 THICK

ISOTHERMAL TEST-PYROFOIL

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611407-12B

IMPEDANCE SLEEVE DESIGN

THERMAL AND NUCLEAR ANALYSIS

R. R. Holman

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SCHEMATIC OF LATERAL SUPPORT AND SEAL SYSTEM WITH WRAPPER

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ESTIMATED AXIAL PRESSURE DISTRIBUTIONS

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ESTIMATED CORROSION OF WRAPPER PYROFOIL O.D. SURFACE (60 MINUTES OPERATION)

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NRX-A6 RADIAL POWER PROFILE -DRUMS AT 115°

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NRX-A6 REZONED CORE, AXIAL PROFILE OF BORE TO INTERSTITIAL PRESSURE DIFFERENCE

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ESTIMATED AXIAL PRESSURE DISTRIBUTION DISTRIBUTIONS

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SUMMARY

W. G. Roman

NRX-A6 DESIGN SUMMARY

1. INCREASE INTERSTITIAL PRESSURE

A. INCREASE AFT END BUNDLING

AFT END PERIPHERAL SEAL

PYRO FOIL WRAPPER

B. INCREASE ORIFICE PRESSURE DROP

C. FLATTEN POWER PROFILE - REZONE

D. GROOVE ELEMENTS AT STATION 10

2. HELIUM INJECTION

3. HOT END CLUSTER SEAL EXPERIMENTAL PROGRAM

611407-28B

TECHNICAL RECOMMENDATIONS AND PREDICTIONS

W. H. Esselman

611417-1B

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PROGRAM PLANNING AND RECOMMENDATIONS

H. F. Faught

NERVA REACTOR SUMMARY SCHEDULE

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NRX-A6 HARDWARE

Power Test 07/21/67

	Design Release Expected	Demand RAL Hardware Release *	Expect RAL Hardware Release	Slack - Week
1. Cluster Support				
Support Block	11/15/66	05/02/67	04/15/67	+2.5
Metallic Protection Cups	10/14/66	04/15/67	04/15/67	0
Carbon-Carbide Protection Cups				
Full Reactor	10/15/66	05/02/67	06/20/67	-3.0
Half Reactor	10/15/66	05/02/67	04/18/67	+6.0
2. Fuel Elements				
PAX	10/22/66	03/01/67	03/01/67	0.0
Core - Fueled	10/22/66	05/02/67	05/02/67	0.0
Centrals	11/01/66	05/02/67	04/15/67	+2.5
LASL	12/01/66	03/27/67	03/27/67	0
3. New Orifice Distribution	10/30/66	03/17/67	03/17/67	0
4. Filler Strips				
Coat	10/14/66			
Modification	11/12/66	05/02/67	04/15/67	+2.5
5. Filler Strip Particle Catcher	11/19/66	05/02/67	04/15/67	+2.5
6. Grafoil Wrapper - Material	10/14/66			
Wrapper	01/25/67	05/02/67	04/05/67	+3.8
7. Aft End Bundling -				
Seal Segment Grooving	11/12/66	02/09/67	01/01/67	+5.5
8. Gas Injection				
Outer Reflector Ring	10/12/66	02/09/67	12/01/67	+10.0

* Based on compressed RAL schedule

GEH/jal
10/10/66

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