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March 1965

Westinghouse Astronuclear Laboratory

MASTER

HHT-7 FILLER STRIP CORROSION TEST RESULTS
BUILD NO. 1 TEST NO. 1

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HHT-7 FILLER STRIP CORROSION TEST RESULTS
BUILD NO. 1 TEST NO. 1

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P. Cherish
W. B. Painter
Fluid Flow Laboratory
Experimental Engineering Department

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by authority of D O C
H.F.C. FC date SEP 10 1973

SPECIAL REREVIEW
FINAL
DETERMINATION
Class: U

Reviewer KAW Class. U Date 2-20-82

Approved By:

E. A. DeZubay
E. A. DeZubay, Manager
Fluid Flow Laboratory

INFORMATION CATEGORY

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ABSTRACT

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Experience in reactor tests to date indicate that high temperature corrosion of graphite material in a hydrogen atmosphere will be a major factor limiting the life of current reactor designs.

In order to increase the life of current reactors it is necessary to understand corrosion phenomenon in regions representative of the reactors.

In an effort to study core peripheral corrosion, a test program was initiated to design, fabricate and test a small diameter filler strip test model having compound components representative of the current reactors.

The results obtained from the preliminary tests show that the concept of using a small diameter core model with components representative of the reactors is feasible in demonstrating corrosion phenomenon in the core peripheral region, and that this program will provide some of the much needed qualitative information to evaluate peripheral designs by comparison with the NRX-A2 reactor configurations and also in advanced reactor design configurations.

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1.0 INTRODUCTION

Post test disassembly of the NRX-A2 reactor revealed severe corrosion at the core peripheral regions. In an effort to study core peripheral corrosion, a filler strip corrosion test model was designed. The model is designed so that it can be tested in the A-10 Single Cluster Corrosion Furnace. The first design made maximum use of existing furnace components and was made with a minimum number of modification. Succeeding designs may require more extensive modifications.

The fixed dimensions of the furnace and existing components dictate that the model be limited to 47-inches long, rather than the full length. Test section diameter was limited to a nominal 5.75-inches.

The purpose of this report is to summarize the results of the preliminary tests completed in the HHT-7 test program. HHT-7, Build No. 1 Test No. 1 is the first of a series of tests tentatively planned to be conducted in the program.

The primary objective of this test was to functionally check the operational characteristics of the model, including a specially designed radiation type tapered heater element; and secondly, to obtain some qualitative type corrosion data.

The results of the test show that (1) the model and heater element performed satisfactorily, (2) qualitative type corrosion data was limited, and (3) excellent flow patterns were defined as a result of local soot deposits.

2.0 TEST MODEL

Pre test photographs of the HHT-7, Build No. 1 Test No. 1 test model is shown in Figures 1 through 3 and a drawing showing the assembly details is shown in Figure 4. The basic configuration consisted of a 5.75-inch diameter model fitted within the A-10 Single Cluster Corrosion Furnace. Model components included a lateral support system, an unimpregnated inner reflector, and a core. The following is a description of the test model.

2.1 Core

The core assembly consisted of a simulated element assembly made from grade H4LM graphite which was surrounded by twelve (12) simulated filler strip assemblies. The element assembly, which is intended to simulate the reactor core, is hollow in the center to accommodate a graphite heating element.

2.2 Filler Strips (Spacers)

Specially designed single section filler strips 47.00-inches long spanned the simulated element assembly. The filler strips made from Graphitite "G" incorporated reactor grade insulating tile.

2.3 Lateral Support and Seal System

The lateral support system consisted of a felt cushion split ring which is made from grade WDF graphite felt inserted behind the seal segments to preload the seal segments against the filler strips. In addition to providing some preload bundling, the felt cushion provides for the thermal expansion of the filler strips upon heating.

The seal system included a complement of seventeen (17) simulated seal rings which incorporated flow slot depths of 9 mils. Seal rings 1 through 12 were made from ATJ graphite. Seal rings 13 through 17 were made from ZTA graphite.

2.4 Cylinder Assembly

The cylinder which was not impregnated was made from grade H4LM graphite to simulate the inner reflector. The cylinder was segmented in three 120° segments to facilitate assembling the core.

2.5 Sleeve Assembly

The sleeve assembly consists of a thin wall graphite tube made from AGSR graphite which supports the cylinder assembly.

2.6 Heater

A resistance type tapered heating element, 56-inches long was made from Graphitite "G" graphite. The heater element heats the simulated element by radiation. The remainder of the core, i. e., filler strips, etc., are heated by conduction. A post test photograph of the heater element is shown in Figure 5.

2.7 Assembly Clearances

After assembling the core, the cylindrical surface of the core was checked for discontinuities and variations. Feeler gages and micrometers were used to measure flow slot depths and filler gaps within an estimated accuracy of ± 0.5 mils. Average measured flow slot depth was 9 mils; average filler strip gap measured 3 mils.

These measurements included dimensional and weight measurements of the components before and after the test. However, as a result of only slight traces of corrosion in addition to the breakdown of the carbon base cement, post test weight comparisons could not be accurately made.

3.0 INSTRUMENTATION

Parameters measured, in addition to those required for operating the A-10 Single Cluster Furnace, included pressure, temperature, and power measurements. A complete list of the instrumentation together with the location is summarized in Table I.

4.0 TEST PROCEDURE

The operational procedure used for the HHT-7 model test is the same as the procedure adopted by the Fluid Flow Laboratory for the operation of the A-10 Single Cluster Furnace. In general, high pressure hydrogen gas supplied from tube trailers enters the furnace and flows vertically downward through the core interstices where the gas is heated to a specified temperature condition. A schematic of the flow system is shown in Figure 6.

5.0 FLOW TESTS

A total of four (4) runs were completed utilizing an ambient temperature gas supply. The first three of these runs were conducted at intermediate power levels with helium to functionally check the operational characteristics of the model. The fourth run was conducted at approximately the design power level (61.5 KW) with hydrogen. During the runs, outlet pressure was set at 545 psig at a specified flow rate before power was supplied to the heater element.

Furnace outlet pressure, helium and hydrogen orifice pressures, simulated element and cylinder material temperatures, and heater voltage and current were measured on continuous type recorders. In addition to the continuous recorders, the pressure data which included the furnace outlet pressure, and helium and hydrogen orifice pressures were measured also with pressure gages; differential type where required.

6.0 RESULTS AND DISCUSSION

A summary of the hydrogen test data is shown in Table II.

Figure 7 shows a power-temperature time history of the test. The duration of the test at the design power level was estimated at 12 minutes. The temperature-time curve shows that (1) none of the temperatures measured a steady-state condition,

and (2) the tungsten/tungsten-26% Rhenium thermocouples used for the test are limited both in temperature and operating life at the elevated test temperatures. Included on the curve in Figure 7 is an experimentally determined temperature range at which tungsten/tungsten-26% Rhenium thermocouples manufactured under the same specification were reported to have failed, WANL-TME-582.

Figure 8 shows the measured material temperatures compared with the predicted steady-state temperatures. Two material temperatures at each of the axial stations are presented here. The lower temperature being the temperature measured at time, $t = 1335$ hours. The higher temperature measured at time, $t = 1346$ hours. The material temperatures shown in Figure 8 are based on (1) the measured millivolt output of the chromel-alumel thermocouples, and (2) an extrapolated temperature based on the millivolt output of the tungsten/tungsten-26% Rhenium thermocouples. The extrapolated temperature level was determined by evaluating a final temperature and fairing in the intermediate portion of the curve. The final temperature was determined by assuming an exponentially defined heating curve. Knowing any three (3) temperatures in a portion of the curve which is separated by equal time intervals, a final temperature can be evaluated using the following relationship.

$$T_f = T_2 + \frac{(T_3 - T_2)(T_1 - T_2)}{(T_1 - T_2) + (T_3 - T_2)}$$

where T_f = final temperature

T_1 , T_2 , and T_3 are any three temperatures of the curve
separated by equal time intervals.

The results of the tests show that (1) the model and heater element operational characteristics were satisfactory with the exception of the time it requires the test section temperature to reach a steady state condition, (2) qualitative type

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corrosion data was limited, and (3) excellent flow pattern characteristics were obtained as a result of local soot deposits which resulted from the breakdown of the carbon base cements at the high operating temperatures.

Post test photographs of the model taken during the disassembly are shown in Figures 9 through 44.

Figure 9 shows the hot end of the model with one of the cylinder segments (TC1) removed, exposing the lateral support and seal system. Refer to Figure 20 for relative orientation of serialized parts.

Figure 10 shows the model partially disassembled with filler strip, F-3, and one seal segment in each row removed exposing the insulating tile. Note the flow pattern along the length of the exposed filler strip. Soot deposits indicate that the seal segments divert the axial flow radially inward between filler strips in the region in which the seal segments are located. This pattern experimentally substantiates the present hypothesis for evaluating the NRX-A2 peripheral element corrosion flow into the filler strip ledge plenums without great amounts of core inflow, WANL-TNR-199, "NRX-A2 Test Report - Supplement I." Also of interest are the corrosion and/or erosion lines which were noted on the inner face of the felt cushion. The orientation of the lines are in the same angular position as the inter lock face of the seal segments.

Figure 11 shows the exposed surface of the simulated element. Incipient lines of corrosion around the element can be identified in the area in which the plenums formed by the filler strip ribs occur.

A sector of the filler strips is shown in Figures 12 and 13 showing the core interface of the insulating tile. Soot deposited on the tile of filler strip, F-8, clearly defines the thermocouple routing channel.

Figures 14 through 20 show various post test photographs taken of the simulated element. Figure 14 shows the relative degree of corrosion along the entire length of the element in the area in which the plenums formed by the filler strip ribs occur. Enlarged views of the simulated element at station 29.5-inches are shown in Figures 15 through 20 with the breakdown pattern of the C14 carbon base cement in the lobes of the simulated element shown in Figures 18 and 20. A schematic showing the filler strip orientation within the core is shown in Figure 21. The cement, used as a filler for potting thermocouple routing channels was found to be unsatisfactory for use in the simulated element. The cement used as a filler in the walls of the segmented cylinder did not breakdown under the lower temperature conditions and performed satisfactorily.

As a result of the soot deposits from the cement used to bond the insulating tile to the filler strips, excellent flow pattern characteristics were obtained which clearly defined internal flow paths. Soot deposits showing flow patterns between adjacent filler strips and between filler strips and insulating tile are shown in Figures 22 through 24. Figure 22 shows the relative degree of deposit along the length of the filler strips. Figure 23 shows the hot end view, and Figure 24 shows an enlarged view at station 29.5-inches.

Soot deposits were observed in the lateral support and seal regions. In Figures 25 through 41, photographs of each seal ring are presented to show the relative amount of deposits in the land and groove of each seal segment as they occurred in the model. Soot deposits on the middle land of each seal segment shown in Figures 34 through 40, indicate that a flow path existed between the interface of the seal segment land and adjacent filler strip. Two conditions were noted which may have caused this flow path to exist. They are

- 1) Improper seating of the seal segments against the filler strips as a result of insufficient preload generated by the felt cushion.
- 2) Uneven thermal expansion of the filler strips caused by a non uniform temperature gradient in the filler strips with the larger of the two types of filler strips being subjected to the higher temperature.

Figures 42 through 44 show the deposits observed on the inner diameter of the segmented cylinder. Figure 42 shows a full length view showing the relative degree of deposit along the length, and Figures 43 and 44 show the deposits on upstream and downstream side of the sealing surfaces at the hot end of the segmented cylinder, (TC1).

Evaluation of the test results show that the corrosion obtained on the simulated element to be much lower than predicted. Experimental data obtained from the NRX-A2 reactor test show a contrasting difference.

In an effort to explain this difference, the following list of conditions were found to exist which may have inhibited or prevented gross corrosion.

- 1) Early state of equilibrium being obtained between carbon-hydrogen reaction molecules as a result of the low core pressure drop. Low pressure drop was contributed to the gaps created by the segmented cylinders permitting both axial and radial flow paralleling the core proper flow.
- 2) Felt cushion acting as sacrificial material. Hydrogen gas passing through the interlocking faces of the seal segments and reacting with the graphite felt which has a high surface area, forming methane. Methane being the inhibitor.

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- 3) Carbon base cement decomposing allowing the carbon residue to react with the hydrogen gas, forming methane.
- 4) Diffusion of helium with hydrogen. "O"-ring burnout in the upper heater insulator allowing helium to leak into the hydrogen gas stream.

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CONCLUSIONS

From the test results obtained from the Build No. 1 Test No. 1 model the following conclusions are made.

1. The overall operational characteristics of the model and the heater element performed satisfactorily.
2. Traces of incipient corrosion were obtained on the simulated element in the area in which the plenums formed by the filler strip ribs occur. Insufficient quantitative corrosion data was obtained to determine any surface regression patterns.
3. Excellent flow pattern characteristics were obtained from soot deposits which clearly defined various flow paths. Of particular interest is the pattern which shows the axial flow being forced inwards by the seal segments. The residue deposited was attributed to a breakdown of the carbon base cement.
4. The C14 carbon base cement used as a filler for the thermocouple routing channels in the simulated element performed unsatisfactorily. However, the cement used in the routing channels of the segmented cylinder, which was subjected to a lower temperature, worked satisfactorily.
5. The felt cushion used as a simulated lateral support system worked satisfactorily mechanically. However, the question still remains on how effective does the felt preload the core to properly seat the seal segments against the filler strips, and is the pressure drop across the seal great enough to overcome surface friction and seat the seal on the downstream face of the cylinder groove thus preventing an axial bypass flow around the seal.

FUTURE WORK

In an effort to improve the initial design of the HHT-7 model for subsequent tests, several components required redesigning. Based on these redesigns a tentative test plan for subsequent builds was initiated. There follows a description of the succeeding two builds.

1. Build No. 1 Test No. 2: This HHT-7 model will consist of a solid cylinder inner reflector, felt cushion as the lateral support system, a piece of fuel element material, and a variable seal schedule. Flow slots depth in the seal segments will include 11, 9 and 7 mils with number 16 seal ineffective. Core configuration including filler strip geometry, and simulated element will be the same as that used in Build No. 1 Test No. 1.
2. Build No. 2 Test No. 1: This HHT-7 model will consist of spring loaded seal segments, a variable seal schedule, NRX-A3 type filler strips, and either a solid reflector with external mounted plunger-spring assemblies or a stack up ring type reflector with internal mounted plunger-spring assemblies.

HHT-7 Build No. 1 Test No. 1 Instrumentation Summary

Table I

Table I
HHT-7 Build No. 1 Test No. 1 Instrumentation Summary

Instrumentation Number	Type	Range	Location	Measurement Axial (Inches)	Location Angular (Clockwise Looking Downstream) (Degrees)
<u>Temperature</u>					
T1	Chromel/Alumel	0-300° F	Hydrogen Inlet Line	----	----
TC1	Chromel/Alumel	0-50 MV	Segmented Cylinder	23. 65	270
TC2	Chromel/Alumel	0-50 MV	Segmented Cylinder	33. 15	30
TC3	Chromel/Alumel	0-100 MV	Segmented Cylinder	41. 15	150
TC4	Chromel/Alumel	0-100 MV	Simulated Element	14. 15	270
TC5	Tungsten/Tungsten-26% Rhenium	0-50 MV	Simulated Element	33. 15	30
TC6	Tungsten/Tungsten-26% Rhenium	0-50 MV	Simulated Element	41. 15	150
VP3	Pyrometer	-----	Sleeve Surface	33. 15	0
VP4	Pyrometer	-----	Sleeve Surface	41. 15	0
<u>Pressure</u>					
P1	Gage	0-1000 psig	Furnace Inlet		
P2	Gage	0-1000 psig	Furnace Outlet		
DP (1-2)	Gage	(0-25 psi) & (0-200 psi)	Furnace Pressure Drop		
PF1	Gage	0-1000 psig	Hydrogen Orifice Inlet		
PF2	Gage	0-1000 psig	Helium Supply Orifice Inlet		
PF3	Gage	0-1000 psig	Helium Heated Orifice Inlet		
<u>Flow</u>					
W1	Orifice	0-100 in. of H ₂ O			
W2	Orifice	0-100 in. of H ₂ O			
W3	Orifice	0-100 in. of H ₂ O			
<u>Power</u>					
E1	Volt Meter	0-100 volts			
I1	Ammeter	0-100 MV			

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Table II

Summary of Measured Data for Hydrogen Test, HHT-7-1-1-GH₂-1

Instrumentation Number	Location	Time - Hours	
		1335	1346
<u>Temperature - °F</u>			
T1	Hydrogen Inlet Line	50	50
TC1	Segmented Cylinder	345	628
TC2	Segmented Cylinder	662	1286
TC3	Segmented Cylinder	653	1520
TC4	Simulated Element	1329	2100
TC5	Simulated Element	3048	3483
TC6	Simulated Element	3737	3610
VP3	Sleeve Surface	----	----
VP4	Sleeve Surface	----	----
<u>Pressure - psig</u>			
P2	Furnace Outlet	545	545
DP(1-2)	Furnace Pressure Drop	0.5	0.5
PF1	Hydrogen Orifice Inlet	550	550
PF2	Helium Supply Orifice Inlet	550	550
PF3	Helium Heater Orifice Inlet	550	550
	Barometer	14.3	14.3
<u>Flow Rate - lb/sec</u>			
W1	Hydrogen Supply	0.0045	0.0045
W2	Total Helium Supply	X	X
W3	Heater Helium Supply	0.0032	0.0035

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Table II (Continued)

Instrumentation Number	Location	Time - Hours	
		1335	1346
	<u>Power</u>		
E1	Supply Voltage	59.8	60
I1	Current	1070	1050

X - Instrumentation Failure

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Figure 1

HHT-7 Build No. 1 Test No. 1 Filler Strip Corrosion Model

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Figure 2

Core Inlet End View of Model

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Figure 3

Core Outlet End View of Model

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Figure 4

Corrosion Test A-10 Furnace

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Figure 5

Post Test Photograph of Heater Element, Insulator Block, and Heater Plug

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Figure 6

Flow System Schematic

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Figure 7

Power-Temperature Time History

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Figure 8

Measured Temperature Compared With Predicted

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Figure 9

Post Test Photograph Showing Internal View of Core Assembly With Cylinder Segment Removed

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Figure 10

Post Test Photograph Showing Hot End View
of Partially Disassembled Model With One Filler Strip Removed

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Figure 11

Post Test Photograph Showing the Exposed Surface of the Simulated Element

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Figure 12

Post Test Photograph of the Partially Disassembled Model
Showing the Exposed Surface of the Insulating Tile

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Figure 13

Post Test Photograph Showing the Hot End View of the Partially Disassembled Model

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Figure 14

Post Test Photograph of the Simulated Element

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Figure 15

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-2

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Figure 16

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-4

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Figure 17

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-6

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Figure 18

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-8

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Figure 19

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-10

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Figure 20

Post Test Photograph Showing Qualitative Corrosion Marks
on Simulated Element Along Filler Strip Interface, F-12

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Figure 21

Cross-Sectional View Looking Upstream

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Figure 22

Post Test Photographs of Filler Strips Showing Flow Pattern Existing Under the Insulating Tile

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Figure 23

Post Test Photograph of Filler Strips Showing Flow Pattern

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Figure 24

Post Test Photograph Showing Flow Pattern Along Filler Strip, F-11

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Figure 25

Post Test Photograph of Seal Segments, Row 1, Cold End Seal Ring

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Figure 26

Post Test Photograph of Seal Segments, Row 2

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Figure 27

Post Test Photograph of Seal Segments, Row 3

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Figure 28

Post Test Photograph of Seal Segments, Row 4

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Figure 29

Post Test Photograph of Seal Segments, Row 5

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Figure 30

Post Test Photograph of Seal Segments, Row 6

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Figure 31

Post Test Photograph of Seal Segments, Row 7

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Figure 32

Post Test Photograph of Seal Segments, Row 8

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Figure 33

Post Test Photograph of Seal Segments, Row 9

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Figure 34

Post Test Photograph of Seal Segments, Row 10

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Figure 35

Post Test Photograph of Seal Segments, Row 11

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Figure 36

Post Test Photograph of Seal Segments, Row 12

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13-3

13-2

13-1

Figure 37

Post Test Photograph of Seal Segments, Row 13

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Atomic Energy Act - 1954

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Figure 38

Post Test Photograph of Seal Segments, Row 14

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Atomic Energy Act - 1954

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Atomic Energy Act - 1954

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Figure 39

Post Test Photograph of Seal Segments, Row 15

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Atomic Energy Act - 1954

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RESTRICTED DATA
Atomic Energy Act - 1954

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Figure 40

Post Test Photograph of Seal Segments, Row 16

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Atomic Energy Act - 1954

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RESTRICTED DATA
Atomic Energy Act - 1954

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Figure 41

Post Test Photograph of Seal Segments, Row 17, Hot End Seal Ring

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Atomic Energy Act - 1954

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RESTRICTED DATA
Atomic Energy Act - 1954

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Figure 42

Post Test Photograph Showing Soot Deposit
On Inner Surface of the Segmented Cylinder Shell

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Atomic Energy Act - 1954

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

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Figure 43

Post Test Photograph Showing Soot Deposit on Upstream Side of Reflector Land

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Atomic Energy Act - 1954

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

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Figure 44

Post Test Photograph Showing Soot Deposit on Downstream Side of Reflector Land

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Atomic Energy Act - 1954