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FIRST SINGLE CLUSTER CORROSION TEST
WANL HYDROGEN CORROSION TEST FACILITY
(Title Unclassified)

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ABSTRACT

For some time there has been a Nerva Project interest in a facility to hydrogen corrosion test a complete cluster assembly of Nerva fuel elements at high temperature conditions by electrical resistance heating. The first complete cluster test was successfully conducted in a recently installed furnace system on November 24, 1964 with a power supply limited by the current carrying conductor. When the installation of a higher current capacity distribution system is complete, this test system will have the flexibility to accommodate a wide range of useful tests.

This report describes the first cluster test (at 10,000 amperes and 20 volts), the solution to the problem of using graphite-to-graphite chucking contact for transmission of high electrical current to a cluster, and the solution to the critical problem of electrically insulating the metal internal part from its surrounding conducting graphite elements.

The significance of this test is the demonstration of the feasibility that clusters or similar type assemblies can be tested at high amperage, a concept previously considered doubtful. Results of this test indicate that no insurmountable difficulties are expected with cluster testing when the 35,000 ampere distribution system is installed.

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I. INTRODUCTION

A. Background

Single element hydrogen corrosion tests are being performed at WANL as part of a routine Quality Control Program. However, single element tests produce only hydrogen corrosion effects on the internal surfaces of the fuel channel and show no interstitial corrosion effect of the tightly clustered elements. In an attempt to simulate multi-element conditions within the physical space limitations of the single element corrosion furnace, three partial cluster tests were performed. In those tests, a center element was tested in combination with segments of the adjoining elements. The partial cluster tests gave only limited information, devoid of any interstitial corrosion effects, and it was decided to subject complete clusters to hydrogen corrosion conditions.

In order to test complete clusters, a test furnace was built which was large enough to accommodate a test assembly for at least one cluster Figure 1. Various single elements were tested in this furnace as part of a checkout procedure to compare the thermal characteristics of the furnace with that of the standard Quality Control single element furnaces. The element supports used were identical to those used in the single element furnace. The comparisons were very good, Figures 2 and 3.

B. Test Requirement

Full cluster tests were required for hydrogen corrosion data, as well as for the determination of temperature distributions in the cluster itself, including tie rod button temperature and the tie rod coolant

temperature at the exit end of the tie rod. Pressure drop data was also required for both the cold flow and the high temperature conditions. The test reported in this document was the first of a proposed series of full cluster tests designed to furnish a means of evaluating reactor component performance under conditions of high temperature and hydrogen flow.

C. Problem Statement

The primary problem in the first full cluster test was that of heating the cluster by the electrical resistance method. The specific question involved was whether or not the high amperage current, approximately 12,000 amperes for the plugged orifice test, could be transferred across the discontinuities between the power electrodes and graphite fixtures, between the fixtures and the graphite sleeve enclosing the cluster, and between the sleeve and the individual fuel elements in the cluster. The answer to that question would determine whether or not the conventional test rig, Figure 1, could be employed in a full cluster, tested at reactor design flow and approximately 35,000 amps, or whether a new heating concept would be necessary.

II. EXPERIMENTAL EQUIPMENT

A. Description

A complete cluster assembly, with all of its 114 fuel element cooling channels plugged with blank orifices, was installed in the center of the HHT-4 vertical furnace with an assembly arrangement as shown in Figures 4 and 5. Direct current heated the cluster by

electrical resistance through the elements. To match the resistance to the power supply, a supplementary graphite sleeve surrounded the cluster its full length to accommodate the necessary current. Heat generated in the sleeve was thereby transferred into the encapsulated cluster. The individual sleeves, sleeve ring clamps, up and down stream chucks, and nozzle are shown in Figures 6 and 7.

With the limited amount of power presently available to heat the cluster to reactor temperatures, it was necessary to close off all of the element coolant channels. The only hydrogen coolant passages, therefore, were through the tie rod coolant channel, interelement openings, chucking gaps, berlox electrical insulation liner, and sleeve mating faces.

A helium atmosphere was maintained around the cluster assembly to prevent unwanted corrosion. The heated hydrogen gas was discharged into a tee shaped transition and a heat exchanger. It was then filtered and vented to the atmosphere, Figure 8. The entire system was cooled with approximately 500 gal/min. of water.

A pneumatic control system permits varying the flow and pressure as required, and electrical power controls permit varying the temperature and rate at which power is applied to the cluster.

III. DESIGN

A. Electrical Insulation

Of great importance to the success of a cluster test is electrically insulating the metal internals of a cluster while the graphite fuel

sections are heated to test temperatures by electrical resistance. In this test, the hole of a center fuel element was enlarged to permit beryllium oxide and ATJ graphite insulators to be inserted between the pyro-sleeves and the center element, along its entire length, Figure 9. The BeO insulators were used as contact resistors in the cooler regions, and the ATJ graphite insulators were used as annular gap resistors in the hotter regions. The ATJ insulators were machined .100 inch larger on the inside diameter than the pyro-tube outside diameter, to provide a .050 inch arc resistant annular gap.

B. Arc Suppressors

To minimize arcing in the upstream chuck sliding area, eight braided copper cables, rated at approximately 400 amperes each, were connected from the graphite cluster sleeve to a copper shoe, which in turn made contact to the walls of the electrode. Figure 10.

C. Chucking (Figure 6)

All chucks were made from ATJ graphite. The hot end chuck was made to provide a slip fit around the sleeve. As electrical resistance heating took effect, the sleeve expanded into the chuck for better electrical contact and minimization of gas leakage. For additional sealing, an "O" Ring (Buna N) was placed between the chuck rim and electrode ledge.

The cold end chuck was designed to permit movement of the cluster due to thermal expansion. Similarly, an "O" Ring was provided for additional sealing at the entrance to the gripping finger entrance.

also, 3/8-inch diameter graphite plugs were inserted into the sleeve junctions (where the two halves butt together) at both the hot and cold ends, to prohibit gas from leaking through the chuck areas.

D. Temperature Measurement

Three types of temperature measurements were utilized.

(1) Thermocouples (Cr/Al) were placed in the tie rod button tip and at the exit of the tube liner. Both of these malfunctioned and no data was obtained in this area. The reason for their failure was attributed to faulty connections at the cold entrance of the furnace. However, the thermocouple technique of leading the thermocouples down through the center of a hollow tie rod to its tip and also spiraling another lead around the tie rod and thru a support cone had been used previously with success in partial cluster tests.

(2) Thermal capsules were placed at six different locations in the assembly, Figure 11.

(a) Three of these locations were along the axial length of an element facing the center element. Slots were milled out for 15 capsules each at centers of 8, 26, and 42 inches from the cold end.

(b) One location, containing 15 capsules, was placed at the 42 inch center in an element facing outward towards the 4th optical pyrometer slot.

(c) Two other rows of thermal capsules (15 each) were centered at 42 inches in the graphite sleeve. One row was insulated with beryllium oxide, while the other was in direct contact with the graphite. This

was done to determine if electrical current passage through thermal capsule wires had any effect on their temperatures. Unfortunately, the thermal capsules picked for this purpose were over-ranged, as the temperature actually experienced was unexpectedly much lower. Therefore, no comparison was obtained between the insulated and uninsulated thermal capsules.

(3) Optical pyrometry was used to measure the temperature in four 1/8 inch diameter holes along the length of the sleeve and also on the sleeve surface, immediately adjacent to the holes. The holes were drilled to within a 1/8 inch of the cluster.

A temperature profile of the measurements are shown in Figure 12.

IV. TEST APPROACH

A. Operation

The controlling factors in this exploratory cluster test were based on the following operating parameters:

1. not to exceed 130 lb/in² ΔP across the cluster
2. not to exceed 4000°R at the fourth viewport (sleeve holes)
3. not to exceed 12,000 amperes (bus bar limitation)
4. cluster outlet pressure maintained at 550 lb/in²

The system was first checked with cold flow to determine system operability and helium leakage. Power was then interjected at small increments, and kept at their respective levels until the system stabilized.

Operation data was then recorded.

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B. Operation Data

Resistance of cluster and sleeve (by ohmeter) = .002 ohms.

Power started 3:29 PM. Power off 4:13 PM

TIME (PM)	3:27	3:31	3:32	3:34	3:36	3:38	3:45	4:01	Steady State 4:09
HYDROGEN (SCFM)	200	216	214	212	210	196	178	150	150
HELIUM (SCFM)	180	180	180	180	180	180	180	50	60
CLUSTER ΔP (LB/IN ²)	55	62	62	55	50	28	30	-	20
He/H ₂ ΔP (LB/in ²)	0	1/4	1/4	1/4	-	-	-	-	1/4
VOLTS	-	4	10	13	20	19	-	19	19
AMPERES	-	900	3500	8500	11600	10,000	-	9850	9850

Pyrometry Temperature, Steady State at 4:08 PM, is plotted in

Figure 12.

C. Weight Loss Data

	<u>Pre-Test</u> (Grams)	<u>Post-Test</u> (Grams)	<u>Loss</u> (Grams)
<u>Elements</u>			
02-02288 (Center)	372.3	350.5	21.8
09-13259 (Position B)	585.0	584.6	0.4
09-13285 (Position C)	584.3	583.8	0.5
09-12847 (Position D)	619.0	618.5	0.5

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	<u>Pre-Test</u> (Grams)	<u>Post-Test</u> (Grams)	<u>Loss</u> (Grams)
<u>Elements</u>			
09-13283 (Position E)	592.7	591.3	1.4
09-13267 (Position F)	583.3	582.4	0.9
09-12852 (Position G)	609.9	609.1	0.8
		TOTAL	26.3
<u>Support Block</u>			
936J209D	167.2	167.2	0.0
<u>Tube Liner (Non Spiral)</u>			
	28.0	28.0	0.0
<u>Insulating Cup</u>			
	2.5	2.4	0.1
<u>Insulating Washer</u>			
	0.6	0.5	0.1
<u>Support Washer</u>			
	3.0	2.9	0.1
<u>Insulating Sleeves (All)</u>			
	94.8	91.2	3.6
<u>Support Cone</u>			
	5.1	5.0	0.1

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The only significant weight loss was due to corrosion in the hole area of the center fuel element, 21.8 grams. In Figure 12, a comparison of the center fuel element wall thickness versus element length, demonstrates that corrosion took place more extensively through the mid-section. This corrosion corresponds to the higher temperature evident in the same area, from observing the temperature profile curves.

V. RESULTS AND DISCUSSION OF THEIR SIGNIFICANCE

A. Temperature Profile

The temperature profile along the length of the cluster sleeve was different relative to single element profiles. This is seen by comparing Figure 2 with the hole and the sleeve profiles of Figure 12. Four factors were responsible for the extremely non-linear sleeve profile: (1) heat conduction by the cluster graphite supports at the ends of the cluster sleeve, (2) the low power level, (3) the low coolant flow through the tube liner, only, and (4) the gas leakage past the support fixtures. The heat conduction is a result of the large thermal mass provided by the massive graphite supports, Figure 7. The low power level and the low coolant flow are synonymous in that they accentuate the conductive losses; the total power input is not large compared to the conductive losses. Hydrogen leakage past the inlet end cluster support pieces cool the sleeve at each end. Future cluster tests will be run at much higher power levels and coolant flow rates which will also decrease the effect of the graphite heat conduction end losses. Re-design of the graphite supports will also decrease the gas leakage at

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each end of the sleeve. (See part B, P. 11)

It is speculated that the center element temperature profile, inner surface on Figure 12, follows a pattern more independent of the end effects of the graphite supports and of the gas leakage at the low coolant flows tested. The support block, in direct contact with the cluster and having very little contact with the sleeve, exhibited a temperature which fell on the center element profile, linearly extrapolated. The support block face temperature was monitored during the test and remained stable at the value shown in Figure 12. However, future tests are necessary to clarify the significance of this data.

B. Gas Leakage

Much of the hydrogen coolant bypassed the tie rod coolant channel. This was evidenced by the extremely low pressure differential across the cluster. Based on the 20 Psi cluster differential at 0.014 lb/sec hydrogen coolant flow rate, approximately two-thirds of the total coolant bypassed the tie rod channel. Also, leakage from the helium atmosphere, surrounding the test rig, past the outlet support pieces varied from 40 to 80 SCFM during various stages of the test. This leakage can affect the cluster temperature profile. Some redesign has been accomplished in an effort to reduce the gas leakage at both ends of the test rig. The redesign includes "O"-rings at the inlet end and labyrinth grooves and a graphite seal at the outlet end.

C. Electrical Power

The desired electrical power input, approximately 200 KW, was achieved with no problems from the standpoint of transmitting the

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power to the cluster test assembly, Figure 5. Also, the effective resistance, E/I , of the assembly during the test was 0.002 ohms. The resistance had been calculated as 0.0023, based on the net graphite cross sectional area of the assembly and of single elements, and on the observed effective resistance of single elements during similar tests.

The significance of these results is the confidence in the ability of the assembly test rig to heat the cluster under conditions of the higher power levels necessary in testing at increased coolant flow rates. The test assembly can apparently handle much higher currents than the 11,600 reached to date, and the current-voltage relationships can be confidently calculated. The effective resistance of the cluster assembly should be the same in the higher power tests as that experienced in this test since the graphite temperature levels will be approximately the same.

D. Foreign Deposit

When the cluster was disassembled, a grayish white deposit was noticed on the element surfaces at approximately 6 inches from the cold end and even more pronouncedly at approximately 42 inches from the cold end, Figures 13, 14, 15 and 16. A spectroscopic analysis of this deposit determined that graphite was the major constituent, with Niobium carbide

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as a minor, and sodium radical reported as a trace. By studying Figure 17, it can be seen that a pattern trace has been established, whereby gas (helium atmosphere) had evidently entered through the sleeve half junctions into the element planes and discharged downstream through the cluster. The temperature profile, Figure 12, may help explain the presence of this deposit in the two areas, since these two areas probably have the same temperature reaction conditions. Therefore, for certain foreign elements in helium gas, there is probably a temperature band whereby these contaminants are plated out.

E. Electrical Insulators

Even though the beryllium oxide ceramic insulators had been used before and had initial cracks, they withstood this test very well. There was some flaking which is depicted by the gray flakes in Figure 18. It is believed that BeO insulators are satisfactory to temperatures up to 3900°R. In this same figure are ATJ graphite annular gap resistors, which performed beyond all expectations. By substituting pyrographite instead of ATJ, electrical gap protection of the metal components should be possible in excess of 4500°R. The black dust collected is from the upper ATJ insulator which happened to have the thinnest original sleeve thickness.

F. Arc Suppressors

The arc suppressor cable system Figure 19 shows that seven of the eight connecting bolts (stainless steel) had melted apart. On future tests this can be eliminated by having the bolts secured into a electrical

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distributing ring, which directly contacts the graphite sleeves. Fixture tests with much more hydrogen coolant flow will also reduce the tendency of cable melt failure. It is noted that minor localized arcing (pitted effect area) had taken place on the graphite chuck surface.

G. Component Analysis

All cluster components survived the test without any apparent physical damage. The greatest weight loss was experienced in the internal hole of the center fuel element, 21.8 grams.

H. ΔP Loss

The ΔP and hydrogen flow data obtained in this test are not suitable for tie rod-tube liner design verification, since considerable hydrogen passed thru the element plane faces and through the chucking.

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VI. CONCLUSIONS

1. A significant technical accomplishment has been established to heat clusters by electrical resistance.

2. It is predicted that high amperage (greater than 35,000) and approximately 80 volts can be successfully induced into clusters.

The achievement of temperature levels approaching those expected in the reactor will be possible with the increased power supply.

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FIGURE 1

HHT-4 CLUSTER FURNACE

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FIGURE 2

HHT-2 COMPARED WITH HHT-4 FURNACE PROFILE

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FIGURE 3

HHT-2 COMPARED WITH HHT-4 FURNACE PROFILE

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FIGURE 4

CLUSTER CHUCK ARRANGEMENT

FIGURE 5

ENCAPSULATED CLUSTER ASSEMBLY WITH CHUCKING

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FIGURE 6

CLUSTER CHUCKS, NOZZLE, SLEEVE HALVES, AND SLEEVE HOLDER RINGS

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FIGURE 7

CLUSTER CHUCKS, NOZZLE, SLEEVE HALVES, AND SLEEVE HOLDER RINGS

FIGURE 8

SINGLE CLUSTER FURNACE GENERAL ARRANGEMENT

FIGURE 9

ELECTRICAL INSULATORS REMOVED FROM CLUSTER, POST TEST

FIGURE 10

ARC SUPPRESSORS AND HARDWARE SUPPORT BLOCK

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FIGURE 11

CROSS SECTION SINGLE CLUSTER SPECIMEN THERMAL CAPSULE LOCATION

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FIGURE 12

CLUSTER TEMPERATURE PROFILE

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FIGURE 13

CLUSTER POST MORTEM, A

FIGURE 14

CLUSTER POST MORTEM, B

FIGURE 15

CLUSTER POST MORTEM, C

FIGURE 16
CLUSTER POST MORTEM, D

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FIGURE 17

HELIUM GAS LEAKAGE PATTERN

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FIGURE 18

BERYLLIUM OXIDE AND GRAPHITE ANNULAR GAP INSULATORS

FIGURE 19

ARC SUPPRESSOR CABLES, POST TEST

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DESIGN

TEST CAPABILITIES

CURVE A: 64% FLOW, 100% TEMP., 2.8 M. W.

CURVE B: 80% FLOW, 100% TEMP., 3.6 M. W.

(LIMITED TO WANL 0.2 LB/SEC HYDROGEN FLOW AND OPTIMUM OPERATING CONDITIONS.)

CURVE C: 75% FLOW

FIGURE 20

TEST ELECTRICAL POWER LIMITATIONS

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