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WANL-TME-1606

April 19, 1967

Westinghouse Astronuclear Laboratory

MINUTES OF INSTRUMENTATION REVIEW MEETING
AT SACRAMENTO ON MARCH 7 AND 8, 1967

(Title Unclassified)

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at Sacramento on March 7 and 8, 1967", dated April 19, 1967

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Transmitted herewith for your information are ten (10) copies of the
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Respectfully,
ORIGINAL SIGNED BY
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April 19, 1967

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SECTION I

HIGH TEMPERATURE THERMOCOUPLE INSTRUMENTATION QUALIFICATION FURNACE

1.0 HIGH TEMPERATURE INSTRUMENTATION QUALIFICATION FURNACE PRESENTATION

During December 1964, it was decided that a separate facility was needed for developing, calibrating, and qualifying temperature sensing devices in a simulated reactor environment. This type of testing was then being done in the hydrogen corrosion furnaces of the Thermo Flow Lab and were tentatively proposed for inclusion in the low pressure hydrogen furnaces of the Engineering Mechanics Department. Because of previously assigned work, particularly fuel element testing, it was difficult to schedule the instrumentation testing. Also, these furnaces were not entirely suitable for the instrumentation work.

In this newly designed furnace, ease of installing and removing the test piece along with the thermocouples was emphasized. High performance in terms of low power at required temperature was specified as well as axial temperature distributions similar to those found in the reactor. A minimum time for the furnace to reach stable temperature and to cool down after testing was considered important to effective operation. Ability to thermal shock the test piece without damage to furnace components was shown to be a specific need (150°F per second). The test piece was specified to be up to 60 inches long and 1-1/2 inches in diameter. This test piece was required to be electrically insulated and to be heated by a radiant heater up to 5000°R at the hottest axial location at pressures up to 750 psi in a hydrogen atmosphere. All components in the hot areas of the furnace were designed to withstand the corrosive effects of hydrogen for a reasonable length of time, say 10 hours.

This furnace (Figure 1), 8 feet long and 8 inches in diameter inside, is designed to heat test pieces as long as 72 inches up to 5000°R at working pressures up to 750 psi in hydrogen. The furnace features an electrically energized heater element, test piece and radiation heat shield assembly, all supported only from above in the top of the furnace, each free to expand thermally without restriction. The test piece can be observed with optical pyrometers through view ports at 13 axial stations. Hydrogen, or other gases compatible with the test piece, are introduced through the test piece, through the view ports, and into the top of the furnace.

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Figure 1. High Temperature Qualification Furnace

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In addition, gas is flowed from a ring nozzle at the top of the test piece inside the heater element to control axial temperature distribution. The mixed gases flow out through an Inconel tube in the bottom end closure, pass through a heat exchanger, and exhaust through a stack. The pressure wall of the furnace is of 3/4 inch stainless steel with 3-1/4 inch flanges bolted to end closures. It is coded to operate at 1100 psi at 1100°F. The bolted bottom end closure is Inconel. The top end closure (Figure 2) is carbon steel commercial tube turns hinged closure, which allows easy access for loading and removal of heater element, test piece, and thermocouples and periodic changing of the radiation heat shield assembly. The tube turn closure assembly is coded at 800 psi and 500°F. The pressure vessel, the view ports, and the bottom end closure are water jacketed.

The vertical position of the furnace is necessary to make possible suspension of the heater element, the test piece, and the radiation heat shields from the top in the cool region of the furnace, quite unaffected by the high temperatures below. The design success depends heavily on a hollow hairpin electrical resistance heater element (Figure 3) fabricated basically from 3-inch and 5-inch graphite logs, 66-inches long. The continuous slot forming the hairpin allows a view of the test piece, suspended inside the heater element, through the ports.

The electrodes of water-cooled copper design are threaded into the heavy sections of the heater element where a minimum of heat is generated. Since the heater is supported only from the top, it is completely free to expand and to contract. Niobium carbide coating protects the graphite heater element from hydrogen corrosion. The heater element is tapered to establish certain basic axial temperature distributions.

The test piece assembly to be mounted in the heater consists of three major components; the core element, the extension, and the plenum.

The elements are reactor rejected core elements in which thermocouples are inserted in plugged holes similar to reactor assemblies (Figure 4).

Fresh hydrogen is supplied to the thermocouples by flowing hydrogen into the top of the element and exhausting down the center of the element through a molybdenum guide tube. A molybdenum tube, inserted in the element center hole protects the element I.D. from hydrogen corrosion. The tube is surrounded by pyro tile to reduce the radial heat losses from the element to the exhausting hydrogen. A molybdenum guide tube welded to a hollow stud is

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Figure 2. Furnace with Blastmat Partially Closed

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Figure 3. Graphite Heater Element

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Figure 4. Test Piece Breakdown Stainless Steel Plenum

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threaded into the bottom of the element and inserted in a hole in the bottom of the heater. This device provides positive centering of the element and an exhaust path for the hydrogen (Figure 5).

The thermocouple, located at the test control station, extends upward through a graphite extension supported by an aluminum sleeve and terminates in a stainless steel plenum. The graphite extension provides an extension of the plenum to the element to allow insertion of the element to the proper depth in the furnace. The extension is drilled similar to the element to facilitate thermocouple alignment and support. The element to extension joint is reinforced with a graphite support block fitted about it and sealed with a high temperature graphite cement.

The plenum provides a strong top support for the assembly. In addition, it acts to supply hydrogen at constant pressure insensitive to pressure surges and is a housing for thermocouple leads and connectors. The plenum wall is machined to accommodate four four-pin Bendix pressure tight thermocouple connectors. The plenum lid was tapped for the hydrogen inlet line. Also a bleed line was attached to a hydrogen to helium differential pressure transducer for control purposes.

The plenum, extension, and element are tied together with a support rod which threads into the top of the element. This assembly provides a graphite housing for test thermocouples while ensuring a supply of fresh hydrogen to the thermocouples.

The inside of the furnace is lined with aluminum oxide tubes; a one-foot high stack of aluminum oxide discs insulate the bottom of the furnace. In the top of the furnace, the five-inch diameter section of the heater element is surrounded by Fibre Frax tubes and cones which function effectively as thermal and electrical insulators.

Suspended from the stack of aluminum oxide tubes lining the furnace, a refractory metal radiation heat shield 45 inches long is positioned centrally in the furnace. This assembly consists of nine concentric tubes of molybdenum and tungsten sheet 0.005 inches thick with tungsten on the inside layers and is fabricated with loose fitted tungsten studs and nuts and hung from a molybdenum cone support (Figure 6).

The heat shield is fitted closely around the heater element; diametral clearance

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Figure 5. Test Piece Assembly Stainless Steel Plenum

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Figure 6. Radiation Heat Shield

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where the heater element is untapered is 1/2 inch; spacing between shields is 0.090 inch (Figure 7). This heat shield together with effective thermal insulation at the top and bottom accounts for the furnace's high performance (Figure 8). The furnace operates at design temperature with an electrical input of as little as 50 KW. The power supply consists of three 40 KW commercial welders.

The equipment exterior to the furnace, in addition to the power supply, consists of flow loops of stainless steel hardware incorporating Research valves with Moore positioners in turn actuated by Moore controllers. Flow measurement is made with Daniel orifices in conjunction with Barton differential gages, and at the very low flows, with Hastings flowmeters. (Figure 9). Auxiliary equipment (shown on Figure 10) includes regulators, pressure relief valves, rupture discs, hydrogen indicators, Hastings flowmeter (to detect leaking valves), vacuum pump, and various water system items. Six strip recorders in the control room register furnace and test piece temperatures continually. The furnace is visible from the control room through 1-1/4 inches of tempered Herculite glass further protected by armor plate fitted to leave a vertical slot in the middle of the window through which the ports are observed when the test piece temperatures are measured optically. (Figure 11).

The primary pyrometer is a Leeds and Northrup single adjustment, potentiometer-type which is mounted on an adjustable swivel base. This assembly is permanently mounted in the control room and observations are made manually through the Herculite window and recorded in the test log. Sets of temperatures are recorded periodically (normally every five minutes once at temperature) with each set consisting of temperature at each port or element position, i.e., Station 45, 39, 32, 26, 20, etc.

Serving as a backup device to the manual optical is a Leeds and Northrup Mark I Precision Automatic Optical Pyrometer, stationed in the cell on a tripod mounting (see Figure 12). This instrument is positioned at the primary station for each test. The primary station is the depth at which the primary test thermocouple is inserted in the element. The automatic optical pyrometer continuously monitors the element temperature at the thermocouple tip and records this output in millivolts on a standard Leeds and Northrup 0 - 50 millivolt recorder. The accuracy of this instrument is claimed to be governed by the calibration and stability of the

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Figure 7. Heater and Heat Shield Assembly

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Figure 8. Furnace Power Supply

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Figure 9. Furnace Control Valves and Gages

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Figure 11. Control Room Optical Pyrometer

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Figure 12. Leeds and Northrup Mark I Optical Pyrometer

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standard lamp and is generally accepted to be the same as the single adjustment pyrometer ($\pm 36^\circ$ at 4600°F). Response time is claimed to be one second and experience show this to be an extremely desirable feature as slight changes in flow or power settings are immediately recorded. The automatic optical pyrometer will be the primary temperature detecting device as soon as a permanent mount and remote controls now being fabricated can be installed.

Startup of the furnace was during the Spring of 1966. Operation was successful at once, a design temperature level of 5000°R was realized, the furnace structure operated cool, there were no pressure sealing problems or arcing. However, during the first series of de-bugging tests, several problems became apparent.

The axial temperature profile was not within specification as the maximum temperature did not occur at Station 45. Test Build 5, Run 2 (Figure 13) shows a typical profile achieved during these early tests with the hot spot generally occurring in the vicinity of Station 32.

The heat shields initially used were not the standard 0.005 inch thick shield design as procurement difficulties forced the use of 0.002 inch thick shields and graphite felt-type shields so that furnace startup could be accomplished.

The coated heaters, acceptable during the early tests since other components were failing more frequently, proved to be unsatisfactory due to severe peeling of the coating.

The test piece assembly was unreliable for several reasons:

The hydrogen flow down the center of the element caused a radial heat flux through the element which contributed to thermocouple error.

The carbon cement used to seal the joint between the plenum and element proved brittle when subjected to the vibration, torsion and excessive temperature variation experienced during assembly and furnace operation.

High hydrogen to helium pressure differentials caused numerous breakouts through the element wall allowing hydrogen to impinge on the heater contributing to coating peeling and heater erosion.

The assembly's stainless steel plenum was heavy and cumbersome contributing to element breakage and excessive assembly time both in building the test piece and loading the furnace.

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Figure 13. Test Axial Temperature Distribution Compared to NRX Temperature Distribution

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The unacceptable axial temperature gradient, hot spot location, and the excessive hydrogen blowouts or pinholing in the thermocouple element were particularly troublesome. It appeared that the heat radiated in the vicinity of Station 45 (maximum resistance of heater) generated a severe vertical convective heat flux such that the hot spot consistently moved upward to the vicinity of Station 32.

A series of tests was conducted with the primary purpose of correcting these difficulties by varying furnace flow rates and power settings without a major redesign of any furnace components.

This series of tests revealed:

Varying the gas (helium) flow into the top of the furnace had little overall effect on the gradient and hot spot. However, careful temperature measurement showed this increased flow tended to move the hot spot toward the desired position. This later proved to be an important factor in achieving specified furnace conditions.

The magnitude of the helium flow through the ports had no effect on the critical conditions but a flow of 0.014 lb/sec of helium cleared the ports effectively for accurate optical pyrometer readings.

Varying the hydrogen flow through the test piece element had the most significant effect on the gradient and hot spot location. By increasing this flow, the element acted as a heat exchanger cooling the upper end of the element and forcing the hot spot toward Station 45.

However, the side effect of the increased flow was completely undesirable. To accomplish these increased flows, the hydrogen to helium differential pressure was increased causing accelerated element erosion and subsequent failure. Thus, increasing the hydrogen flow to improve temperature conditions jeopardized the entire test. It proved more desirable to reduce the hydrogen flow and differential pressure to a minimum for use on an environmental condition only and not as a control method.

The other alternatives for achieving an acceptable axial temperature gradient and hot spot location were modifying the heater profile by a trial and error method to generate the desired hot spot or introduce a direct counter flow to the convective heat flux. The latter approach would confine the heat in the vicinity of Station 45 as indicated on an earlier test

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when flow was increased in the top of the furnace. Modification of a heater requires many weeks of machining and assembly but introducing a counter flow was achieved quickly and easily.

A ring-shaped nozzle with six 60-mil jets located on each element flat was designed and fabricated about the top of the element and positioned below the element and extension joint and is shown in Figure 14. The helium previously put in the top of the furnace was diverted through the nozzle.

This device dramatically produced a controllable hot spot and an acceptable temperature gradient as indicated in Build 11, Run 4 (Figure 15). The hot spot could be positioned from Station 32 to the end of the test piece by varying the helium flow through the nozzle.

This feature and the reduction of the hydrogen necessary to simulate desired conditions led to the redesign and specification change of the Test Piece Assembly which resulted in a substantial reduction of material cost and assembly time.

Redesign of the test piece proceeded as follows:

Since the H_2 flow was minimized, the center exhaust was not required; therefore, the H_2 flow down the center of the element was stopped and the only hydrogen flowing is that which moves down the thermocouple hole and permeates through the element wall (Figure 16).

The moly tube, pyro tile, and spacers were eliminated from the element center hole and the element was tied to the chamber assembly with a support rod threaded into the top of the element and a reinforcing pressure seal. (Figure 17)

All unused holes in the element were plugged with graphite shim stock to decrease the amount of H_2 flowing thus reducing the amount of corrosion. Also, the center hole of the element would be plugged at the bottom since a reliable seal could not be achieved in the threaded section of the support rod. A 10-inch tantalum tube is inserted 26 inches deep in each test element to confirm the presence of hydrogen.

The plenum was redesigned to allow faster and more reliable assembly and reduce the weight of the test piece. This was accomplished in the following manner. The two-piece stainless steel plenum was replaced with a three-piece aluminum plenum. This provided better accessibility to the thermocouple leads and connectors besides substantially reducing the weight and

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Figure 14. Helium Diversion Nozzle

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Figure 15. Test Axial Temperature Distribution Compared to NRX Temperature Distribution

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Figure 16. Test Piece Breakdown Aluminum Plenum

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Figure 17. Test Piece Assembly Aluminum Plenum

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cost of the piece. The 12-inch machined graphite extension was replaced with a 1-inch aluminum thermocouple guide. The support block and graphite cement were replaced by heat shrink tubing and Dow Corning 890 RTV silastic rubber adhesive (Figure 18). This low temperature pressure seal was possible due to the ring nozzle placed directly over it.

The finished test piece provided a light, inexpensive and reliable fixture for testing thermocouples which could be assembled in half the time required for the old design. To ensure repeatability of test conditions, a Hastings flowmeter was installed in the H_2 line to record the mass rate of flow permeating through the element. The control of the furnace was now based on the helium flow through the nozzle and the power input. The hydrogen flow was reduced to that required to ensure a continuous supply of fresh hydrogen about the test thermocouples. This is achieved by maintaining a positive hydrogen to helium pressure differential.

With the elimination of test piece failures, the peeling of the heater element coating mentioned earlier became a major deterrent to continuous testing. With the increased frequency of tests and severe cycling requirements, the useful life of the heaters decreased to approximately two one-hour tests. It became apparent that the cause of coating failure was not due to H_2 corrosion since this was minimized with the test piece redesign, but to severe temperature cycling. The obvious solution was to eliminate the coating. Success was immediate. The first uncoated heater put in the furnace in October 1966 functioned satisfactorily through January 1967 with no evidence of corrosion or arcing. An adequate supply of uncoated heaters is on hand to guarantee a year of continuous furnace operation.

Unsatisfactory heat shield performance experienced throughout the greater part of the shakedown period was eliminated with the delivery of several "standard" and experimental shield assemblies in October 1966. The procurement of these heat shields was accomplished after many months of coordination and effort between WANL's Engineering and Purchasing Departments and the shield supplier, Richard Brew Company, Concord, New Hampshire.

This buyer-supplier understanding has been developed to the point that new or rebuilt heat shield assemblies can be delivered four (4) weeks from date of order. Also, the shield performance is outstanding as they proved to be five times more durable than originally expected. Both an uncoated heater and a standard heat shield assembly have achieved over 50 hours of satisfactory test operation with maximum test temperatures ranging from 4600 to 5000°R and

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Figure 18. Test Piece and Ring Nozzle Assembly

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no evidence of corrosion or distortion apparent.

2.0 OPERATIONAL STATUS

With the use of the stable furnace components and test fixtures, a period of two weeks for trial thermocouple tests was required to establish necessary flow and power values to achieve simulated non-fueled nuclear reactor engine conditions.

Normal operation procedures were standardized and tests conducted as specified in the Process Specification 294657, August 31, 1965, which specifies thermocouple qualification standards.

The thermocouples are built to the Thermocouple Build History Sheet and assembled in the test piece as shown on the test piece assembly sheet (Figure 19). This assembly is then mounted into the furnace (Figure 20). The furnace is made ready for test via the High Temperature Qualification Furnace Operation Procedure, Revised Issue February 1, 1967.

Power is then introduced at a conservative rate. The temperature at the control station is brought up to 1000 degrees below test temperature and the furnace allowed to stabilize. During this period, flows are adjusted to achieve a satisfactory axial temperature profile and hot spot location (Figure 21). When this is achieved and the furnace appears to be functioning normally, power is increased until the temperature at the control station approaches test temperature; then power is cut to a level necessary to maintain test temperature.

Normally, development and qualification tests consist of four 15-minute cycles at a specified temperature. The first cycle usually requires minor adjustment of power and flow settings to achieve satisfactory conditions. During the second, third, and fourth cycles temperatures are achieved in one step with no intermediate stops.

Test data sheets, cyclic, and deviation curves are issued for each test (Figures 22 and 23).

The control station, test temperature, test objectives, and date of test are predesignated by the thermocouple development engineer and the test engineer and schedules are issued on a monthly basis (Figure 24).

October 15, 1966, the High Temperature Qualification Furnace became fully operational as a reliable facility for qualifying core element thermocouples with excellent repeatability of axial temperature gradient and hot spot location.

DWG/SKETCH NO. & REV: NONE BUILT BY: R. KAUTZ
SHEATH MAT'L: TANTALUM START DATE: NOV. 4, 1966
SHEATH P. O. NONE COMPL. DATE: NOV. 16, 1966
SHEATH DIMENSIONS NOMINAL: L = 42" O. D. .098 I. D. .078
VENDOR: MEASURED L = 42" O. D. .098 I. D. .078
SHEATH CONDITIONING: RINSE ACID, H2O FLUSH, BASE FLUSH, SANDBLAST
WIRE TYPE: W WIRE DIA: .040 MIL WIRE LOTS (+/-): ?

INSULATORS	MAT'L	VENDOR	P.O. NO.	O.D.	I.D.	COND.	LGTH.
HOT END	BeO	COORS	45872	069	043	BAKED OUT	42
MIDDLE	NONE						
LEAD END	STAINLESS						20

TRANSITION DIA: 110 MIL SHEATH DIA: JCTN +5" +10" +15" 20

ASSEMBLY TECHNIQUES: DRY BOX-AIR X DRY BOX-INERT

OPEN AIR GLOVES X OTHER

BRAZE TYPE & ALLOY: INDUCTION BRAZE 1170°F SILVER SOLDER

EVACUATION & FILL GAS: CYCLES NONE GAS --- PRESSURE (GAGE) ---

LOOP RESISTANCE: BEFORE JCTN --- AFTER JCTN .4 FINAL .4

INSULATION RESISTANCE: WIRE TO WIRE --- WIRE TO SHEATH ---

FLOATING T/C ---

JUNCTION TYPE: GROUNDED TIP PLUG MT'L: W

LEAK TEST: NO X-RAY REQUIREMENTS NONE

SPECIAL INSTRUCTIONS:

Ta GOLD PLATED ON COLD END FOR BRAZING OF STAINLESS STEEL
TRANSITION.

COPPER WIRES BRAZED ON END FOR ASSEMBLY INTO TEST FIXTURE.
SEALED WITH POXY ON END.

THIS T/C WAS OLD R-6 BROKEN IN ASSEMBLY FOR TEST. REPAIRED AS
OF THE DATA ABOVE.

APPLICATION: STA 45 MAX. TEMP. 4600°R USE DEV. TEST

611575-71B2

Figure 19. Thermocouple Build History, Serial No. TCR6A

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<u>IDENT.</u>	<u>DATE</u>	<u>DRAWING NO.</u>	<u>STATION</u>	<u>LEVEL</u>	<u>S/N</u>
1166D6	11-21-66	R-6 DUAL PROBE	45	IX	
	He	Z-20	45	1 HR. 2 CYCLES	

BUILT 11-17-66 BY E. P. BAUMANN

R-6 PLACED IN TEST PIECE IN FLAT A HOLE NO. 2 - AT 45" REAMED AND PLUGGED

R-6 PLACED IN TEST PIECE IN FLAT F HOLE NO. 2 + 45" REAMED AND PLUGGED

Z-20 PLACED IN TEST PIECE IN FLAT D AT 45" REAMED AND PLUGGED

TANTALUM PLACEMENT IN TEST PIECE IN FLAT B AT 26" AND PLUGGED

LENGTH OF TANTALUM APPROXIMATELY 10"

ALL REMAINING HOLES IN TEST PIECE PLUGGED THEIR ENTIRE LENGTH

TEST PIECE NUMBER UN 02-94924

THE PRE-TEST R OF R-6

+ TO -0.7 $\sim$

+ TO G 0.1 $\sim$

- TO G 0.5 $\sim$

THE PRE-TEST R OF Z-20

+ TO -3.3 $\sim$

+ TO G 1.0 $\sim$

- TO G 2.9 $\sim$

THE POST-TEST R OF R-6

+ TO -10.4 $\sim$

+ TO G 0.6 $\sim$

- TO G 20.0 $\sim$

THE POST-TEST R OF Z-20

+ TO -3.5 $\sim$

+ TO G 0.9 $\sim$

- TO G 3.0 $\sim$

PRESSURE TESTED TO 10 ASSEMBLED ON AN ALUMINUM PLENUM.

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Figure 21. Station 45 Thermocouple Tested in Hydrogen at 600 psig

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DATE: 11-22-66

PURPOSE: 1. EVALUATE THE DUAL PROBE (R-6) AND THE Z-20 THERMOCOUPLES
TO 4600°R IN A HELIUM ATMOSPHERE.

TEST PIECE: UN 2-94924

CONDITIONS: ALL HELIUM AT 600 PSIG.

HELIUM: THROUGH TEST PIECE INTITAL 9000 CC/MIN. INDICATED

$\Delta P11$ 30" H_2O INDICATED

$\Delta P21$ 11" H_2O INDICATED

THERMOCOUPLE DESCRIPTION:

PRIMARY T/C: R-6

DWG:

IDENT. NO:	R-6	Z-20
STATION:	45	45
CONDUCTORS:	40 MIL W/W26% Re	17 MIL W/W26% Re
INSULATORS:	BeO	BeO
SHEATH:	Ta	Ta
COATING:	NONE	NONE

RESULTS: 1. BOTH COUPLES COMPLETED TWO 30 MINUTE CYCLES AT 4600°R
INDICATING APPROXIMATELY 200°R LOWER THAN OBSERVED BY
OPTICAL PYROMETER.

2. THE R-6 DUAL PROBE COUPLE OPERATED ERRATICALLY ON HEAT
UP AND COOLDOWN OF BOTH CYCLES.

Figure 22. Test Number: E & I - 1166D6 FFL: Build 14 Run 4

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Figure 23. Deviation Curve for Station 45 Thermocouples
Tested in Hydrogen At 600 PSIG

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<u>IDENT.</u>	<u>DATE</u>		<u>DRAWING NUMBER</u>	<u>STATION</u>	<u>LEVEL</u>
	<u>TARGET</u>	<u>TEST</u>			
1166D1	11/1/66 He	10/31/66	Z19 SK.Z-8 Z21	39 39	IV 15 MIN. MINIMUM
1166Q2	11/3/66 H ₂	11/1/66	T & K 928F613 R-8 V. D. W/Re	45 42	IXA*
1166D3	11/7/66 H ₂	11/4/66	R-14 DUAL PROBE R-11 V. D. W/Re	39 39	VIII 1 HR. MAX. 4 CYCLES+
1166D4	11/10/66 H ₂	11/8/66	R-2 9 MIL W OUR Ta R-16 G. E. EXTRUDED W	39 39	VIII 1 HR. MAX. 2 CYCLES
1166Q5	11/15/66 H ₂	11/14/66	(KAUTZ) 928F613 978D272	45 45	IXA*
1166D1 RUN 2	He	11/17/66	Z-19 Z-21	39 39	IX X
1166D6	11/21/66 He	11/21/66	R-6 DUAL PROBE Z20	45 45	IV 1 HR. 2 CYCLES
1166D7	11/29/66 He	12/1/66	R-13 G. E. EXTRUDED W G. E. HAFNIA* Z-12 (TA) SK. Z-8	26 45 45	VIII 1 HR. 2 CYCLES
1166D8	11/30/66 H ₂	12/2/66	R-17 G. E. EXTRUDED G. E. HAFNIA	32 45	IXA*

*PRIME THERMOCOUPLE

611575-74B

Figure 24. Thermocouple Test Schedule for November

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SECTION II

CLUSTER EXHAUST GAS THERMOCOUPLE FOR XE-1 APPLICATION

1.0 INTRODUCTION

This portion of this report discusses the design, development, and qualification testing of the cluster exhaust gas thermocouple and its support assembly. The purpose of this thermocouple is to provide diagnostic temperature data about the unmixed exhaust gas in XE-1. Eventually, if proven to be reliable during the XE-1 test, it may be considered for backup for control purposes.

In order to verify the design of the cluster exit gas temperature measurement system, testing was planned:

1. to study the effect of the measurement system on the structural integrity of the cluster in which it is installed;
2. to determine the ability of the measurement system to mechanically survive the XE-1 environment;
3. to determine if thermocouple output is reliable for diagnostic and control purposes.

In order to evaluate the design of the measurement system, four types of tests are required. These tests which were planned to be consistent with the requirements of Process Specification 294657 along with the current XE-1 plan are: (1) Instrumented Cluster, (2) Cyclic Temperature and Stress, (3) Combined Cyclic Temperature and Stress, and (4) Vibration.

2.0 INSTRUMENTED CLUSTER TESTS

2.1 Discussion

These instrumented cluster tests were considered the most important and a major portion of the program was devoted to them. The object was to evaluate a full cluster assembly and the gas temperature measurement system when subjected to simulated XE-1 thermal and flow conditions. These tests were conducted in the single cluster furnace in the WANL Fluid Flow Laboratory Hydrogen Facility. (See Figure 25.)

This furnace is designed to accept a single instrumented cluster. The furnace is shown in position in the test cell. The installation of the thermocouple with its support

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Figure 25. Single Cluster Cell Furnace

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assembly in the cluster was identical to actual reactor installation. The cluster is electrically self-heated. The central element is made of beryllium oxide in order to insulate the tie rod from the electrodes. Hydrogen flow is provided from tank trucks. A sight port at the bottom end of the furnace permits the use of an optical pyrometer to read the temperature on the aft end surface of the support block.

A typical test cycle consists of two 20-minute cycles at full power. Between cycles, the cluster assembly is usually removed for inspection and to change fuel elements. Full power conditions are attained when the exit gas temperature reaches 4285°R . The goal is to accumulate at least 40 or more minutes at full power unmixed exit gas temperatures which is 10 minutes longer than the current XE-1 Test Plan. This facility cannot be temperature cycled as heating and cooling causes cracking of the elements in the cluster and subsequent electrical arcing in the furnace.

2.2 Test Results

2.2.1 Introduction

At the March 1966 Instrumentation Review Meeting, the first six preliminary tests of this program were discussed. During these tests, one major component of the support assembly was an extended pyrolytic graphite cup. Its function was to thermally protect the tie rod cone and thermocouple support components. This cup corroded progressively during these tests. It was replaced by a gas-cooled tungsten coated molybdenum cup in the tests now under discussion. Other configuration changes in support hardware were made to improve the design.

A typical instrumented cluster assembly for the January 24, 1966, test, which was reported during the last meeting, is shown in Figure 26 for review. This assembly includes the extended pyrolytic cup which is no longer used.

2.2.2 Test No. 1 - April 15, 1966

Test No. 1 of the present series was conducted on April 15, 1966. This test included exit gas thermocouple 979D149 H02D (Figure 27). This thermocouple has a 62.5 mil diameter tungsten - 26% rhenium sheath with a 14 mil thick wall. The thermoelements are 5 mil diameter tungsten - 26% rhenium and tungsten wires. They are enclosed by BeO insulation and are welded at the tip to form a plug-type thermocouple junction.

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Figure 26. Typical Instrumented Cluster Assembly

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Figure 27. 979D149H02D - Effluent Thermocouple

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The extension lead is 40 mil diameter stainless steel sheath with MgO insulation. The stainless sheath is transitioned to the refractory metal sheath with a stainless steel sleeve and the assembly is joined by brazing.

The support assembly for this test included several modifications based on knowledge gained from previous tests. The modifications include:

- 1) The use of a standard NRX-A5 insulating cup rather than the extended pyrolytic graphite cup previously employed to protect the tie rod cone and the thermocouple support.
- 2) Inclusion of two rows of holes near the base of the molybdenum protection cup to allow cool gas from the tie rod channel to flow outward into the annulus between the insulating cup and the molybdenum cup.
- 3) Enlargement of the flow holes in the thermocouple support to provide additional coolant flow around the thermocouple braze joint.

This test was held at steady state for 30 minutes. Temperatures 200°R lower than desired were attained because of an erroneous recorder reading. The thermocouple EMF output was steady and continuous during the entire test cycle. Correlation between the exit gas thermocouple output and that of a downstream W/W-26%Re thermocouple was within 435°R . After correcting for the effect of the tie rod coolant flow on the cluster exit gas temperature, the two indicated temperatures are within 165°R .

Figure 28 shows the thermocouple and support assembly after the 30 minute power test. The insulating cup lost most of the coating on its outer surface but very little corrosion occurred. No cracks were noted in the molybdenum cup; however, the thermocouple sheath and support were blistered on and near the flange of the support. (Figure 29). The blistering was caused by temperatures in the vicinity of the flange and cup-gas interface that were much higher than those sensed at the thermocouple tip. This occurred because radiation heat losses from the surface of the cluster assembly result in a significant radial temperature gradient. This gradient causes the flow through the outer circle flow holes which is sensed

Figure 28. Thermocouple and Support Assembly After 30 Minute Power Test

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Figure 29. Blistering of Thermocouple Sheath and Support

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by the thermocouple tip to be cooler than the flow through the inner circle flow holes. The flow through the inner circle flow holes impinges on the flange and past the cup-gas interface. The actual temperature of the coolant flow leaving the inner circle flow holes is unknown. The condition of the flange indicates that it may be in excess of the flange design point. It is concluded that the test conditions were more severe than those predicted for XE-1.

The EMF output record for the first cycle is shown in Figure 30. The assembly was rebuilt with new fuel elements for the second cycle but was not tested because the thermocouple tip was bumped and broken during installation into the furnace.

2.2.3 Test No. 2 - April 27, 1966

This test included a tungsten sheathed thermocouple part number 979D149 HO1C and a modification of the thermocouple support. The flange on the radially outward face of the thermocouple support was removed in favor of a conical design. The object being to reduce the cross sectional area available for heat transfer toward the braze area of the thermocouple. In all other respects the assembly was identical to the previous test of April 15.

This test plan specified a 5 to 10 minute full power cycle followed by a 20 to 30 minute full power cycle. During the first cycle, control was maintained on the exit gas thermocouple; however its output decreased instantly to zero after indicating 3850°R and furnace control was shifted to power correlations from previous tests. After 8 minutes at steady-state temperatures estimated at 4000°R , power was gradually decreased to zero. During the power decrease and subsequent cool-down, the thermocouple apparently formed a new junction. When output resumed, it indicated a temperature of 2480°R . It then tracked the power decrease smoothly to zero.

After Cycle I, the tungsten thermocouple sheath appeared slightly blistered. Other components in the measurement system appeared to be undamaged by the test. After visual inspection, it was decided to continue into Cycle II without a cluster disassembly and detailed inspection.

In the second cycle, the thermocouple EMF output was smooth up to 3750°R and then it again decreased instantly to zero. This test continued for about 16 minutes at temperatures estimated at 4000°R . During this portion of the test, a high helium leak rate

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Figure 30. Exit Gas Thermocouple 979D149H02D (S/N A48865) Output Record HHT-4-20a

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occurred and power had to be adjusted up and down repeatedly for 16 minutes in an effort to stop the leak. Finally, the test was terminated when it was realized that the leak was caused by fractured elements. Temperatures of the gas varied between 2400°R and 4200°R during this period.

Post-test inspection revealed several elements were fractured, presumably on the down-ramp of Cycle I. The thermocouple, molybdenum cups, and thermocouple support were melted slightly as shown in Figure 31. During disassembly the tip of the thermocouple fractured near the support. The tungsten sheath tip is shown in an enlarged view in Figure 32. The molybdenum protection cup was cracked from the slot in the trailing edge to the first row of holes.

The graphite support hardware was essentially intact except for coating peeling from the insulating cup. The radial temperature gradient effect which was discussed previously is suspected as being the cause of melting near the support.

2.2.4 Test No. 3 - May 13, 1966

Test No. 3 on May 13, 1966 included a tungsten - 26 percent rhenium sheathed thermocouple. The support hardware was the same as Test No. 1 (April 15, 1966) except that it included a non-flanged thermocouple support and employed the insulating cup from that test rather than a new one. Thermocaps were inserted in the center element to measure the radial temperature gradient.

The test continued at full power for 21.5 minutes and was automatically terminated because of an overheated power supply. During the test the thermocouple EMF output was smooth and continuous and tracked all power changes. The steady-state temperature was approximately 4260°R . The EMF output record is shown in Figure 33.

Very little damage was experienced by the measurement system except for insulating cup corrosion and slight blistering of the thermocouple sheath near the support. Figures 34 (a) and 34 (b) illustrate the post-test condition of the assembly.

Thermocapsule data indicated that the temperature on the inner surface of the elements at Station 52 was from 4500°R to 4600°R . This would indicate that a gradient of

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Figure 31. Melting of Thermocouple, Molybdenum Cups, and Thermocouple Support

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Figure 32. Enlarged View of Tungsten Sheath Tip

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Figure 33. Thermocouple EMF Output Record

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Figure 34 (a). Post-Test Conditions of Assembly

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Figure 34 (b). Post-Test Conditions of Assembly

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200°R to 300°R could have existed from the tip of the thermocouple to the thermocouple support. The support may have reached 4600°R. This would explain the localized blistering of components apparent in this and prior tests.

This cluster was stored and later rebuilt with new elements and retested on September 8, 1966. During the second cycle, this thermocouple operated satisfactorily at the outset. However, it failed before test temperatures were attained. After the test, it was found that the thermocouple tip fractured. The exact cause of the fracture was not determined but it is suspected that handling of this assembly during the four-month delay between Cycle I and Cycle II may have resulted in damage to the thermocouple.

2.2.5 Test No. 4 - October 22, 1966

Test No. 4 on October 22, 1966 included a 979D149 HO2 exit gas thermocouple and had a support assembly that differed from the previous assembly in several respects.

A curved plate was installed with a relatively close fit over the thermocouple support, as shown in Figures 35 (a) and 35 (b), which is illustrative of the assembly used for this test. The purpose of this curved plate or molybdenum baffle is to prevent hot gasses from flowing through the slot in the molybdenum liner cup and subsequently impinging on the thermocouple support and tie rod extended cone.

Secondly, a slotted collar or orifice sleeve was installed on the end of the tie rod cone to provide flow impedance for the tie rod exit gas flow. This component diverts a large portion of the tie rod flow over the thermocouple.

In addition, it also causes a slight over pressure to occur within the molybdenum liner which ensures that hot gasses would not tend to flow inward toward the transition joint and tie rod cone. The orifice sleeve utilized in this test was threaded over the tie rod extended cone as shown in Figure 36.

Finally, molybdenum bushings or spacers were installed around the thermocouple tip inside the molybdenum support. These spacers forced the transition joint away the hot gas stream and in addition, it served as an impedance to the conduction of heat along the thermocouple sheath toward the transition joint.

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Figure 35 (a). Curved Plate for Thermocouple Support

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Figure 35 (b). Assembly View of Curved Plate for Thermocouple Support

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Figure 36. Threaded Orifice Sleeve for Tie Rod

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This test was successfully conducted at a cluster exit gas temperature of 4290°R for a total steady-state power hold of 21 minutes. The thermocouple operated continuously throughout the entire power cycle of 34.0 minutes which included start-up and shut-down ramps and holds at intermediate power levels.

Post test inspection of the assembly revealed that the thermocouple and support were essentially intact but the molybdenum liner cup, tie rod cone, and inconel orifice sleeve were melted as shown in Figure 37. Analysis of the configuration design resulted in the conclusion that the clearance between the orifice sleeve and molybdenum was too small. The cup apparently touched the sleeve during the test and the heat flux by conduction through the molybdenum cup melted the sleeve and tie rod cone. When the molten metal from the cone and sleeve wet the molybdenum cup a lower temperature eutectic was formed between the molybdenum and the inconel which subsequently resulted in the melting of portions of the molybdenum cup.

2.2.6 Test No. 5 - October 31, 1966

Test No. 5 was run on October 31, 1966. The support assembly and thermocouple for this test were essentially the same as the previous test except for modification of the inconel orifice sleeve. In this assembly the sleeve was not threaded on to the tie rod cone. In addition, the material was changed from inconel to molybdenum and the clearance between the sleeve and liner cup was increased. The increased clearance was to prevent contact with the liner cup while maintaining adequate flow impedance for the tie rod exit gas flow.

This test included two cycles and a total time under power of 64 minutes was attained. The thermocouple responded to all temperature changes during the test and indicated temperatures continuously.

A maximum temperature of 4350°R was indicated during the second cycle for about 6 minutes. The total steady-state time was 36.7 minutes at temperatures greater than 4283°R . Figures 38 (a) and 38 (b) illustrate that no damage was sustained by any of the components of the thermocouple assembly as a result of the two test cycles.

Figure 37. Melting of Molybdenum Liner Cup, Tie Rod Cone, and Inconel Orifice Sleeve

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Figure 38 (a). Undamaged Thermocouple Assembly After Testing

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Figure 38 (b). Undamaged Thermocouple Assembly After Testing

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3.0 CYCLING TEMPERATURE AND STRESS TESTS

3.1 Discussion

The purpose of this test is to demonstrate the resistance of the tungsten - 26 percent rhenium sheath of thermocouple 979D149 HO2D to cyclic mechanical loads after being cyclic heated above its recrystallization temperature. Two exit gas thermocouples were included in this investigation.

For the cyclic temperature portion of this test, the object was to cycle a thermocouple from ambient to approximately full reactor power unmixed exit gas temperature of 4285°R at least eighteen times.

This test was conducted in a helium atmosphere in a bell jar which is shown in Figure 39. The exit gas thermocouple was supported in a manner that permitted an electrically heated tungsten coil to enclose it. A close-up, without the bell jar, shown in Figure 40, illustrates the test arrangement. Three equally spaced jets that direct helium on the 1850°F melting point braze are apparent. This coolant flow prevents heat radiation from the tungsten heating coil and conduction along the thermocouple's axis from melting the braze. The test is performed by rapidly applying a predetermined current to the tungsten coil from a direct current welder. The test temperature is controlled by using the output of the test thermocouple. During the first test the current was removed as soon as the thermocouple output indicated a temperature greater than 4000°R. The second thermocouple tested was held for short periods of time at elevated temperatures because the introduction of cryogenically cooled helium flow insured adequate cooling of the braze joint. The first test employed ambient helium flow.

The cyclic stress test was planned to simulate the pressure and friction drag forces on the thermocouple caused by flowing hydrogen. It was performed after the cyclic temperature test and when the thermoelements and sheath were recrystallized.

This test was conducted by firmly holding the thermocouple in a collet while it was subjected to an equivalent distributed force. A controlled concentrated force was slowly applied by a force indicator scale attached to a micrometer feed mechanism. The load was

Figure 39. Exit Gas Thermocouple Cyclic Temperature Test Arrangement

Figure 40. Close-up of Heater Coil and Coolant Arrangement for Exit Gas Thermocouple Cyclic Temperature Test

slowly removed and the procedure repeated. Each thermocouple was subjected to four stress-ing cycles. Figure 41 illustrates the test arrangement during a typical cycle. The mechanical load was equivalent to the calculated aerodynamic load.

3.2 Test Results

The first thermocouple tested was identified as No. 22 and is shown in Figure 42 after the cyclic temperature test. This instrument was subjected to twenty (20) thermal cycles at indicated temperatures greater than 3900°R . The EMF output record for the last 20 minutes of a 68-minute test is shown in Figure 43. This portion of the output record is also representative of the EMF output during the first 48 minutes of the test.

During the aerodynamic load simulation test a force of 0.25 pounds was applied at a distance of $13/32$ inch from the braze joint. This force causes the same maximum deflection in a cantilever beam as distributed load resulting from 8 psi on the projected area of the thermocouple. Calculations indicate that the total drag because of normal pressure and tangential stresses on the thermocouple is equivalent to 8 psi on the projected area.

The 0.25 pound force was applied for three cycles and was followed by one 0.30 pound cycle. Figure 44 illustrates the 0.30 pound cycle.

The complete EMF output record of the second thermocouple, identified as No. 17, is shown in Figures 45 and 46. It includes at least 20 cycles above 3900°R and up to one minute holds at elevated temperatures. Improved cooling of the brazed joint permitted these holds. Figure 47 illustrates the post-test condition of the thermocouple.

The force simulation test was performed in a manner similar to the previous test. After the cyclic stress test on No. 17, a cyclic temperature test was repeated to acquire more confidence in the design. During this test much higher indicated temperatures were achieved. Figure 48 illustrates the EMF output record. This test culminated when an indicated output of 4540°R was recorded for 30 seconds.

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Figure 41. Test Arrangement During a Typical Stress Test Cycle

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Figure 42. Thermocouple No. 22 After Cyclic Temperature Test

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Figure 43. Output Record of Exit Gas Thermocouple No. 22

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Figure 44. 0.30 Pound Stress Test Cycle

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Figure 45. Output Record of Exit Gas Thermocouple No. 17 For First Half of a 40-Minute Test

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Figure 46. Output Record of Exit Gas Thermocouple No. 17 For the Last Half of a 40-Minute Test

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Figure 47. Post-Test Conditions of Thermocouple

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Figure 48. Output Record of Exit Gas Thermocouple No. 17 After Cyclic Stress Test

4.0 COMBINED CYCLIC TEMPERATURE AND STATIC LOAD TEST

4.1 Discussion

This test consisted of cyclic heating a thermocouple from ambient to elevated temperatures, while applying to it a constant dead load. The purpose of the test was to evaluate the structural integrity of the thermocouple when subjected to simulated thermal and mechanical reactor full power conditions.

The test arrangement for the combined high temperature and load testing of a thermocouple is shown in Figure 49. The major components of this assembly are (1) a bell jar, (2) a tungsten heating coil, (3) the thermocouple and coolant jet supports, (4) a cooled helium supply system, (5) a dead weight loading system and, (6) the associated instrumentation.

A constant dead load equivalent to 1.4 times the calculated aerodynamic load of 8 psi was applied 13/32 inch from the braze joint by a pulley system. The temperatures experienced by the thermocouple were indicated by the thermocouple itself.

4.2 Test Results

A summary of this testing is:

- 1) Eight temperature cycles from ambient to 3640°R with a total of 5-1/4 minutes at 3640°R .
- 2) Five temperature cycles from ambient to 3940°R with a total of three minutes at 3940°R .
- 3) Nineteen temperature cycles from ambient to 4300°R with a total of 32-3/4 minutes at 4300°R .
- 4) Temperature transients of at least 500°R per second.

The performance of the thermocouples was satisfactory during this test and post-test evaluation indicated only slight sheath distortion but no other damage.

Figure 50 illustrates this post-test condition.

Figure 49. Thermocouple Arrangements for Combined High Temperature and Load Testing

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Figure 50. Post-Test Thermocouple Sheath Distortion

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5.0 VIBRATION TEST

5.1 Discussion

An extensive vibration test was conducted at the WANL Engineering Mechanics Laboratory. The thermocouple and its assembly were subjected to two resonance surveys and several sweep tests. A resonant frequency of 3085 cps was determined and the assembly was vibrated for 20 minutes at this frequency with a controlled 10g input. Throughout all testing the thermocouple survived over 5-1/2 million sinusoidal vibration cycles at levels in excess of 5g's.

The electrical resistance of each thermoelement to the sheath and across the thermoelements was measured before, during and after the test. This measurement and the appearance of the thermocouple was not affected by these tests.

6.0 CONCLUSIONS

It is concluded that exit gas thermocouple 979D149 HO2D and its support assembly are qualified for inclusion in XE-1. All testing was planned and conducted to fulfill the minimum requirements of Process Specification 294657. In addition, special tests not included in the qualification test specification were also conducted to further verify the design.

This thermocouple which has a tungsten-26% rhenium sheath with a 14 mil wall thickness, repeatedly demonstrated that it can provide reliable data up to 4300°R when subjected to environmental conditions considered more severe than XE-1. Twenty-one of these thermocouples have been installed in the XE-1 reactor.

One thermocouple 979D149 H01C, which has a wrought tungsten sheath with a 10 mil wall thickness was determined inadequate for XE-1 application. Its degraded condition after test 20a was not entirely explainable and excessive temperature can be only partially suspected. No further tests are planned for the tungsten sheathed thermocouple design at this time as performance of the tungsten-26% rhenium sheathed thermocouple demonstrates qualification to the present temperature level requirements. This work is reported in TME-1386, Addendums 1 and 2.

7.0 DEVELOPMENT PROGRAM

An exit gas thermocouple has been developed that eliminates the 1850°F braze joint of the 979D149 design. This was accomplished by replacing the stainless steel transition with a moly-rhenium transition tube. The moly-rhenium is joined by electron beam welding to the tungsten-26% rhenium and to the sheath lead by brazing. This results in a very high temperature welded joint in place of the 1850°F brazed joint. In addition, the moly-rhenium to stainless steel sheath joint is repositioned to a lower temperature region. Figures 51 and 52 illustrate the design. Continued development and testing of this design would provide basic information for candidate related thermocouples for PFRT design verification tests (Figure 53).

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Figure 51. Development Model-Effluent Thermocouple

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Figure 52. Development Model-Effluent Thermocouple

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Figure 53. Longitudinal Section-Electron Beam Welded Transition For Exit Gas
Thermocouple ID 0.035 Inch

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SECTION IIIA STRAIN GAGES

1.0 INTRODUCTION

Strain measurements are required within the pressure vessel of the NERVA reactor for the following reasons:

- 1) To determine the magnitude and frequency of radial displacements of the core components.
- 2) To measure both static and dynamic strains in structural members of the core caused by variations in temperature and fluid pressures. This information is necessary for verification of reactor design calculations and will serve as a basis for improved designs.

Locations where strain measurements are presently planned are:

- 1) Lateral support springs
- 2) Core tie rods

2.0 STATE-OF-ART

An irradiation test performed on weldable gages at the Plum Brook Reactor Facility resulted in wide permanent zero shift. This test included six weldable gages and four pair of foil Budd gages. Two of the weldable gages were on a static test specimen and the remaining four were mounted on two constant strain beams for a compression and tension test.

Each of the weldable strain gages indicated a permanent zero shift between 1100 and 3800 microinches at the end of the test which appeared to be a linear function of the integrated neutron flux. A similar effect was seen in the Budd C9-610 gages but the permanent zero shift was less than 300 microinches.

3.0 DEVELOPMENT PLAN

The exact cause of zero shift in the weldable gages has not been determined. It is postulated that the shift may be caused by inadequate quality control in the strain gage manufacturing process and particularly the assembly of the strain gage sensing element and MgO

in the strain tube. The compaction of the sensing element and metallic oxide power in the strain tube is obtained by use of a programmed high speed centrifuge and an elaborate swaging operation.

Microdot postulated that the cause might be due to effect of radiation on the active filament which might differ from the effect on the dummy filament. The active filament in the strain tube is a straight wire and the dummy is a coiled configuration.

In addition, the active and dummy filaments have different temperature coefficients of resistivity because of their heat treatment history. This is the method used to achieve temperature compensation. It is conceivable that radiation might produce an equivalent change in the molecular and crystalline structure of the wire as does the heat treatment. If the two filaments experience the same change due to radiation, then the bridge balance, which is determined by the resistance ratio of the two, should not change. This of course, is contrary to the radiation test data. Possibly the radiation affects one filament differently than the other because of heat treatment history and configuration. A test program has been devised to investigate the hypothesis. This program should result in a better understanding of the behavior of the filament component of the gage during irradiation. Quarter-bridge unmounted gages which have different heat treated filaments will be studied for radiation effects. If the results indicate that the filaments are unaffected by radiation, then subsequent tests will investigate the quality control postulation.

4.0 FUTURE WORK

An experiment in LASL's Omega West Reactor is being planned to study the effect of radiation on both the active and dummy filaments. The details of this test program are in progress and tentatively include:

- 1) establishing a test procedure,
- 2) modifying existing fixturing,
- 3) ordering and procurement of hardware,
- 4) conducting the test,
- 5) and the final evaluation report.

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The results of the LASL Omega West Tests will be evaluated and compared to the previous tests. It is possible that a better explanation of the zero shift in the Plum Brook Tests will result from this comparison.

Part of the test program includes gages that have platinum-tungsten alloy filaments and in a special case, a pure platinum filament. The purpose of this investigation is to determine effects of radiation on various strain filament materials. The information obtained from this effort will be used to upgrade current designs. It should be recognized that this program may be only a starting point for evaluating and determining the effects of radiation on only one strain gage component. Subsequent tests to study the radiation effects on elasticity of MgO and its strain transmitting properties may be required to explain the zero shift problem completely.

A solution based on a more complete understanding of zero shift in weldable Microdot strain gages is considered imperative for PFRT design verification tests.

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SECTION IIIB

ANGULAR POSITION TRANSDUCER

1.0 PURPOSE OF TRANSDUCER

The purpose of this program is to develop a transducer to measure the angular position of each driver and driven control drum in NR-1. The current NR-1 design includes 24 drums. (Six or perhaps four) of these are to be driven by actuators mounted externally on the pressure vessel. Eighteen (or twenty) of the follower drums will be ganged with the driver drums with endless bands to complete the ganged control drum system.

Reactor control requirements include the knowledge of the angular position of all 24 drums during reactor operation. Drum binding can be determined only by knowing the position of each drum at all times. A decoupling mechanism disengages a driver shaft when rotation is impeded by a sticking drum when a predetermined torque is exceeded. The normally operating drums would continue to change angular position as indicated by the position transducers.

Each actuator has an integral potentiometer which indicates the position of the actuator shaft. The potentiometer provides no information about the position of the follower drums since the state of the decoupler mechanism is not always known. Position measurements for each of the 24 drums which is completely independent of the decoupling mechanism are required for accurate and reliable drum position information during reactor operation.

2.0 PRELIMINARY DESIGN REQUIREMENTS

The preliminary design requirements are the following:

- a) Mechanical: accuracy - 3% in 180° , rotation - 0° to 180° , resolution - 1° ,
- b) Environmental: temperature - 200°R gaseous hydrogen, components - must survive nuclear environment, pressure - 700 psia, vibration - 10 g to 2000 cps

3.0 DEVELOPMENT SPECIFICATION

The tentative development specification for the angular position transducer is now in progress. The mechanical and environmental conditions specified in the design requirements

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will be included in the development specification. As development discussions continue with potential vendors, the specification will be upgraded to be more compatible with modifications in the design.

4.0 VENDOR SURVEY

A preliminary investigation has indicated that three devices are being considered for candidate transducers. Each device has advantages and disadvantages and will have its own electrical requirements.

The potentiometer, with a 0 to 180° mechanical track, appears as the most promising device because of its several advantages. Vibration effects can be eliminated due to a double wiper system. The potentiometer is small in size and relatively low in cost. It has a 3-conductor lead and has DC excitation. The case of the potentiometer is readily adaptable to an open case design making coolant flow possible. A major problem with the standard potentiometer is that organic components must be replaced by ones that will survive a nuclear environment. Cryogenic temperature performance must be explored because it may cause binding in the instrument bearings. Two other problems are commutation and power dissipation behavior in this severe environment.

The encoder has one main advantage in that its output is digitized. The problems associated with the potentiometer are basically those of the encoder. Furthermore, in addition to its larger size, the encoder requires multiconductor leads (about 11 leads).

The LVDT has been proved functionable in a nuclear environment. The development of a 10 watts per gram design, however, has been disappointing. The LVDT requires a mechanism to convert from angular to linear displacement. The LVDT also requires AC excitation.

5.0 NON-NUCLEAR EVALUATION TEST PROGRAM

The qualification test specification for the non-nuclear tests on development units will be written as part of the work program. Non-nuclear tests on these units will be conducted in conformance with this specification. This activity will include LVDT's that

were ordered in CY '66 in addition to the potentiometer and encoder procured for evaluation.

6.0 NUCLEAR EVALUATION TEST PROGRAM

The preparation for this program is quite extensive since complex fixturing is required to simulate NR radiation conditions. This test would be planned for the Plum Brook Reactor Cryogenic loop and would include the type of transducer that satisfied the non-nuclear test specifications. The performance of the candidate transducer would be evaluated and a formal report issued.

7.0 PROCUREMENT SPECIFICATION

The procurement specification will be updated if required to incorporate the latest developmental information. This updated specification will be used to procure instruments for reactor application. Further nuclear and non-nuclear testing of reactor grade transducers for NR qualification is contingent upon the performance of the candidate instruments during nuclear and non-nuclear developmental testing.

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SECTION IIIC

PRESSURE TRANSDUCERS

1.0 INTRODUCTION

The Westinghouse requirements for a pressure transducer are primarily for diagnostic purposes. The requirements for the diagnostic transducer are $\pm 1\%$ accuracy, and a frequency response from 700 to 1000 cps within $\pm 3\text{db}$.

2.0 REVIEW OF WANL PRESSURE TRANSDUCER DEVELOPMENT

This presentation will review (a) brief performance history of some of the WANL pressure transducers in NRX and PBRF tests; (b) the development progress since the last review meeting in March 1966; (c) the future development program.

In the Design Review Meeting of March 1966, I stated that by looking at the performance history of the transducers on the NERVA tests and at PBRF, the status of the pressure transducer development could be determined. At that time details were given on the performance of all the WANL internally mounted pressure transducers used from NRX-A2 through NRX/EST. The results of the last WANL radiation effects test run at PBRF in November 1965 were also reported at the last meeting.

To minimize repetition and still meet the requirements of this review outline, I will present information again only on the transducers which have indicated good data. We have had four successful NERVA and three PBRF tests to date. The following history is a brief review of the Wiancko transducer performance; since this unit has repeatedly indicated the minimum of combined environmental effects during NERVA and PBRF tests.

Figure 54 shows the comparative results of the same internal reactor pressure measurement using transducers located inside and outside the vessel. In each chart the heavy line indicates the internal transducer; and the thin line indicates the external shielded unit.

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Figure 54. Comparison of Same Pressure Measurement Using Transducers Located Inside and Outside Reactor Vessel

Both transducers were "T"-ed to the same pressure probe measurement line. For each test shown this indicated data are the results of the Wiancko variable reluctance transducer, mounted on the dome end of the shield. Other transducers were used in the same locations, but since their performance was previously reported, it will not be covered extensively here.

From bottom to top the charts indicate NRX-A3, EST, and A-5 results.

The Wiancko internal pressure transducer installed on the dome end of the shield appeared to operate normally during NRX-A3 testing. The plotted data shows a comparison within 25 psi for the Wiancko (P-306) internally mounted transducer with the P-305 externally mounted strain gage type during the EP-V full power run. For an 800 psia unit this is 3.1%, other data shows $\pm 1.6\%$.

The center chart shows a comparison of the internal and external transducers for the NRX/EST (EP-IV) full power run. However, here the Wiancko (P-306) internally mounted transducer indicates a 50 psi higher pressure than the externally mounted unit. A check back to EP-III, EP-IIC, and EP-IA indicates that the Wiancko was also indicating 50 psi higher (this is $+6.2\%$). A comparison of the pre- and post-date system calibrations for this channel indicates some difference in these calibrations; even a small shift in these calibrations could account for a part of this 50 psi difference.

For NRX-A5, EP-IV, the heavy line in the top chart indicates a 37 psi difference, or a 4.6% measurement greater than the external strain gage unit. Again, as in the lower two plots there is a good correlation between the measurements.

The important fact indicated here, is that for installation on the dome end of the shield, the Wiancko transducer will give reliable measurements within the percentages indicated by these plots. It is possible to decrease this percentage - but more than one transducer per vehicle will need to be used for this measurement and more careful pre- and post data system calibrations are needed for each EP.

2.1 Brief Review of the PBRF Test Results

The transducers which were used by WANL for the three PBRF tests were selected as promising candidates based upon their performance in the GTR and NERVA tests completed

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at that time. These transducers were the Wiancko Model 54726, the Consolidated Electrodynamics Corporation Model 171300, the Consolidated Controls Corporation Model 413M31, and Physical Sciences Model PT1001. All of these performed within specification for the non-nuclear evaluation tests; i. e. temperature, linearity and hysteresis, vibration, acoustic noise, and mechanical shock.

Figure 55 shows the best performance attained in radiation heating tests at PBRF. It is to be noted that this is the performance of one transducer tested at Plum Brook, and is therefore not a statistically meaningful curve. It does, however, show the capabilities of one transducer of this design. This transducer can operate continuously at 1.4 watts per gram radiation level and give pressure information within the $\pm 10\%$ error band. This test indicated that neither the Consolidated Controls Corporation nor the Physical Sciences transducers can produce pressure indications as well as the Wiancko at the 1.4 watts per gram level.

The comparative effect of gamma heating on the transducer performances in the November 1965 PBRF test is presented in Figure 56. The curves are approximate average effects as measured on the respective transducer types. They include only the observed rate effects within the capabilities of the transducers in this experiment prior to the failure mode studies. It can be readily seen that the Wiancko transducer affords the highest accuracy performance both from the standpoint of zero shift and sensitivity change. The effects of irradiation rate on measurement accuracy were observed on the respective pressure transducers in this experiment. All three types would operate in NERVA applications, however, it can be seen that the Wiancko design has the least error induced by irradiation rates.

The Wiancko transducer has operated successfully from GTR tests in 1962, through PBRF tests to the latest NRX-A5 test. No other transducer used for NRX development has this performance history. These figures represent the WANL development status as it was approximately one year ago. There has been no WANL radiation effects testing since November 1965.

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Figure 55. Performance of Three Types of Transducers with Approximately Same Gamma Heating

APPROXIMATE GAMMA HEATING RATE -
WATTS PER GRAM CARBON

**ZERO SHIFT
VERSUS GAMMA HEATING RATE**

APPROXIMATE GAMMA HEATING
RATE - WATTS PER GRAM CARBON

**SENSITIVITY CHANGE
VERSUS GAMMA HEATING RATE**

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Figure 56. Performance of WIANCKO Transducer Nov. 1965, WANL 23/W508, PBRF Test

2.2 Development Progress from March 1966 to March 1967

From the NRX and PBRF test data briefly reviewed here, it was shown that the Wiancko transducer could not be expected to operate dependably where the gamma heating rate was above an approximate value of 1.4 watts per gram. Therefore, to meet the diagnostic frequency response requirements the problems were either (1) leave the transducer on the dome side of the shield and use the infinite line* technique, or (2) reduce the internal temperature effects due to gamma heating so that the transducer could be moved to the point of the required pressure measurement.

A re-evaluation of the transducer construction and the heat transfer values involved made it apparent to me that by modifying the present design, the internal temperatures caused by gamma heating could be reduced considerably.

Figure 57 is a review of bourdon tube basics and is also shown in order to clarify transducer terminology used herein in order to explain the design modification. The standard and twisted bourdon tubes are shown as force summing devices, section A and B of the figure.

Normally the pressure is applied to the inside of these tubes; cross sectional view C indicates the resulting oval shape as a dotted outline. This action causes a proportional displacement at the end of the standard bourdon tube as indicated in A. In 1852 Mr. E. Bourdon patented this principle. Some 15 years ago Mr. T. Wiancko twisted a bourdon tube and found it produced a rotational displacement of the armature around the longitudinal axis of the tube in proportion to the pressure applied as shown at B.

Most manufacturers supply pressure transducers like the closed case absolute unit shown at E. The case is sealed around the pressure sensing element, with the reference pressure sealed within the case. The pressure to be measured is applied through long tubes to the inside of the bourdon tube.

When pressure is applied to the outside of these same bourdon tubes, the resulting shape is shown by dotted lines at D. The net effect on the sensing element is the same as if pressure was applied inside the tube.

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Figure 57. Bourdon Tube Basics With and Without Case

The WANL open case design is shown schematically at F. The reference pressure is sealed inside the tube and the measured pressure is applied outside the tube. Reversing the normal application of the bourdon tube in this manner for internal NERVA application, permits reactor coolant to flow around and cool the sensing element. This minimizes internal transducer temperature effects caused by gamma heating. It is to be noted that with this design the transducer must be placed at the point of measurement.

2.3 Accomplishments with WANL Open Case Wiancko Units

Figure 58 shows a calibration curve of a twisted bourdon tube when the pressure is applied from the inside and then from the outside. The transducer which was used was actually a Wiancko 50 lb. ΔP unit. Reversing polarity of the leads for the left hand plot would produce a positive output rather than the negative one shown. This curve proves that pressure applied to the outside of the tube does work.

A comparison of calculated gamma heating effects is shown in Figure 59 for the closed and open case units. Note that the open case design indicates approximately a 760 degree lower internal coil temperature than the closed case (subtract values shown in boxes). With Westinghouse Hyperco replacing the Mumetal "E" cores, this unit could be used in temperatures up to 2238^oR, which is the Curie point of Hyperco. Based on these values, this unit should be able to operate in a gamma heating rate of approximately 30 watts per gram.

The thermal analysis of the WANL modified Wiancko units (979D717 G01 and 980D618 G01) indicates that an internal transducer ΔT of 320^o will be produced in going from a 0.2 to a 4.0 watts per gram level. Comparatively, in the old design this ΔT would be 900^o.

If in the tests discussed above, the actual internal transducer temperatures (during testing) are close to the calculated; then, the thermocouples (one in the center of each transducer "E" core coil) in the transducer in the 0.2 watts per gram region will sense a temperature of 251^o while the other in the 4.0 watts per gram area will sense a temperature

Figure 58. WIANCKO ΔP Transducer

CLOSED CASE WIANCKO
PRESSURE TRANSDUCER -P/N 54727

OPEN CASE WIANCKO
PRESSURE TRANSDUCER P/N 600755

HEAT GENERATION RATE 4 WATTS/GRAM
 TEMPERATURES IN °R
 HYDROGEN COOLANT IS 247 °R

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Figure 59. Comparison of Estimated Internal Temperatures During Irradiation Testing

of 571°. A number 70 screen is used as a case to protect the armature and coils. These calculations are based on an 89% theoretical reduction of coolant through the No. 70 screen. An actual flow test on this screen produced results indicating that the reduction in flow was only 40%. The greater flow through the screen will lower the internal temperature. If these transducers survive the radiation effects, then further development is warranted on the demodulator circuitry so that temperature effects on the transducer coils can be compensated for by circuitry feedback methods.

Construction details can be better seen in Figure 60. The "E" core coils are separate integral coils. Within each there is a C/C thermocouple. These thermocouples will be used to correlate coil resistance changes with temperature so that the accuracy of the pressure measurement can be increased. The old coil and new coil designs are comparable in Figure 61. Two separate encased coils and "E" core designs were required for the new design.

The actual delivered units, WANL P/N 979D717, are shown in Figure 62. These will be used in NRX-A6. One unit will be on the dome side of the shield in a 0.2 watts per gram level; the second unit will be on the core side of the shield in a 4.0 watts per gram region.

The WANL calibration of these first two Wiancko units was extensive. Figure 63 shows a plot of the average results of many cycles for the different indicated temperatures. Figure 64 indicates a method of amplifying the data of the previous curves in order to better see the deviations from a separate straight line for each temperature.

The horizontal dotted lines indicate $\pm 0.75\%$ F. R. linearity and hysteresis specification limits. These curves represent all ninety-nine data points made during the test and not just the best data. Figure 65 indicates how this data looks when averaged and plotted as millivolts deviation from the common ambient straight line for each of the three temperature tests.

Figure 66 will show the effects of immersion in LN₂ directly from room temperature. One thermocouple was placed on the exterior surface of the transducer to

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Figure 60. Open Case Design Details WANL/WIANCKO Pressure Transducer

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Figure 61. "E" Core Integral Coils Old and New Design

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Figure 62. Two WIANCKO Units - WANL P/N979D717

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CALIBRATED OUTPUT DATA AVERAGED AND PLOTTED AS
AMBIENT % F.R. VS PRESSURE FOR EACH TEMPERATURE

Figure 63. Open Case WIANCKO Pressure Transducer Non-Nuclear Environmental Performance

Figure 64. Open Case WIANCKO Pressure Transducer Non-Nuclear Performance Millivolt Deviations from Ambient Straight Line

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S/N 50001

S/N 50004

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Figure 65. Open Case WIANCKO Pressure Transducer Non-Nuclear Performance Average Millivolt Deviations from Ambient Straight Line

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Figure 66. Temperature Shock Test WIANCKO S/N 50004

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indicate the sudden immersion. The two thermocouples A and B, one inside of each electrical coil, indicate a cooldown rate of $10^{\circ}\text{F}/\text{sec}$. The transducer zero output trace at atmospheric pressure indicates a 2.1% of full range zero shift for S/N 50004 and a 6.05% full range zero shift for S/N 50001. The specification limit for zero shift during cooldown is 10%.

The test results tabulated in Figure 67 indicates the non-nuclear performance. The data shown are average values of three cycles for each temperature. The correlation between WANL and Wiancko data is good.

Figure 68 is a comparative tabulation of one open case Wiancko with the closed case Wiancko unit (P-708) used in NRX-A5. The closed case data was taken from the filibration book for NRX-A5. This closed case unit represents a typical unit which Wiancko has been manufacturing for Westinghouse since the GRT tests in 1963. The open case unit represents one of perhaps six (although only three were delivered) which were built on an engineering laboratory basis. Nevertheless, the comparison is good considering these facts.

The results of the NRX-A6 test will prove how compatible these units can be with the nuclear environment.

2.4 Accomplishments with Microdot Open Case Unit

In July 1966 I discussed the possibility of building an open case unit with the Microdot people. Their literature advertised a patented radiation hardened pressure transducer which consisted of a "C" shaped bourdon tube restrained at both ends with weldable type strain gages.

The Microdot weldable strain gages lend themselves ideally to the open case concept, since this type of strain gage is hermetically sealed. Figure 69 shows a view of the proposed design. The full scale view is shown as it may be installed in an inner reflector wall. As the two bourdon tubes are restrained at both ends, the strain gages detect the maximum deflection at the center of the tubes. These tubes have the reference pressure sealed inside.

DESCRIPTION	S/N 50001						S/N 50004						SPEC LIMITS
	AMBT		400°F		-320°F		AMBT		400°F		-320°F		
	<u>W</u>	W	<u>W</u>	W	<u>W</u>	W	<u>W</u>	W	<u>W</u>	W	<u>W</u>	W	
LINEARITY AND HYSTERESIS % F. R.	.24	.27	.58	.26	.30	.42	.37	.30	.71	.41	.37	.43	1.5
SENSITIVITY M. V. D. C.	4994	5071	5377	5359	4692	4710	4999	5248	5289	5569	4749	4868	
RESIDUAL UNBALANCE % F. R.	1.72	.60	5.35	2.86	.60	2.12	1.22	.10	9.5	9.86	.37	.90	4
REPEATABILITY % F. R.	.06 .16	.04	.42		.70		.04 .17	.04	.77		.29		.20
THERMAL ZERO SHIFT % F. R./°F			.011	.73	.0005	.01			.027	.0294	.003	.01	.01
THERMAL SENSITIVITY SHIFT % F. R./°F			.024	.01	.015	.018			.018	.018	.013	.018	.01

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Figure 67. Open Case WIANCKO Pressure Transducers Tabulated Performance Data (Non-Nuclear)

DESCRIPTION	CLOSED CASE	OPEN CASE	CLOSED CASE	OPEN CASE	CLOSED CASE	OPEN CASE	SPEC. LIMITS
	75°F	78°F	500°F	400°F	-320°F	-320°F	
LINEARITY AND HYSTERESIS %F.R.	0.475	0.37	0.30	0.71	0.25	0.37	1.5
SENSITIVITY M. V. D. C.	210.1	4999	211.9	5289	214.6	4749	
RESIDUAL UNBALNACE % F.R.	2	1.22	1.8	9.5	2.2	.37	4
REPEATABILITY %F.R.	.094	.04 .17	.12	.23 .77	.14	.06 .29	.20
THERMAL ZERO SHIFT %F.R./°F			.0026	.027	.008	.003	.01
THERMAL SENSITIVITY SHIFT %F.R./°F			.0015	.018	.021	.013	.01

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Figure 68. Comparison of WIANCKO Closed Case and Open Case Pressure Transducers
 Non-Nuclear Performance Data

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Figure 69. Open Case WANL/Microdot Pressure Transducer Concept

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Figure 70 is a comparison of the closed case and the open case design. Since the open case is so small and weighs one ounce, it is perhaps the most promising candidate.

Figure 71 is a thermal analysis of the Microdot open case design comparing a unit made with stainless steel to one made of beryllium copper. This analysis was done for application in the XE-2 reflector plenum fluid temperature is shown as 180°R. The core exit pressure comes into the cavity through the small end and exerts its force on the outside of the bourdon tubes. The seal at the flange end prevents the higher plenum pressure from leaking past to the core exit. At 4 watts/gram the ΔT across the tubes is 300°, with the high point at 753°R. This is not an adverse workable range for strain gages. This weldable strain gage is unique as compared to other strain gages, in that it consists of a thin wall stainless steel tube which is spot welded to a flange. The strain element is insulated with magnesium oxide, inserted in the strain tube, packed with additional magnesium oxide insulation and mechanically swagged to compact the insulating powder. The assembly is spot weldable to the bourdon tube. The strain gage filament is a nickel-chrome alloy which can be heat treated to adjust its coefficient of resistivity both plus and minus about 0 PPM. This configuration contains no organic materials and is essentially a high temperature device. Such a construction permits adjustment of the heat treat of the strain gage filament after assembly and installation of this strain gage. This heat treat adjustment is made by heating the strain gage to temperature between 700 and 1500°F. Individual heat treatment of the gages used in the pressure transducer is possible even after installation of the gage in the transducer.

The extremely small thermal zero drift achievable by using four active SG 120 type strain gages is possible by individually heat treating the strain gages so that the apparent strain with temperature curve of each of the gages effectively matches the other ones. The resistivity of the strain gage is adjusted to essentially zero microstrain deviation at two temperatures, say for instance, room and -320°F. Between those two temperatures, there is a bow in the apparent strain curve which is essentially the algebraic sum of the non-linearities of the thermal coefficient of resistance of the strain gage filament and the thermal coefficient

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Figure 70. Comparison of Microdot Original Radiation Hardened Pressure Transducer and WANL Concept for NERVA

OPEN CASE WANL/MICRODOT PRESSURE TRANSDUCER

17-4 PH MATERIAL (°R)	BeCu MATERIAL (°R)
1. 795	1. 777
2. 753	2. 750
3. 694	3. 686
4. 627	4. 613
5. 564	5. 540
6. 503	6. 436
7. 447	7. 354
8. 409	8. 294
9. 713	9. 403
10. 398	10. 291
11. 698	11. 399
12. 900	12. 900
13. 650	13. 650
14. 650	14. 650
15. 580	15. 580
16. 480	16. 420
17. 420	17. 420
18. 350	18. 350
19. 300	19. 300
20. 250	20. 250
21. 298	21. 263
22. 180	22. 180

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Figure 71: Thermal Analysis of the Microdot Open Case Design

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of expansion for most metals decreases considerably at low temperatures, but the thermal coefficient of resistivity remains relatively constant. The difference in the apparent strain curve for any two gages compensated to the same resistivity at the two end temperatures is extremely small. That is, the apparent strain curve of any two gages tracks each other within about 5 microstrains, typically, over a 400 or 500° temperature span. Thus, if four identical gages are mounted on the same material in a Wheatstone bridge configuration and exposed to the same temperatures, the net thermal shift is very small. As a practical matter, certain additional errors are introduced because the end points of the apparent strain curves cannot be made to be exactly identical. They are similar enough, however, to provide a net zero shift with temperature of less than .001%/°F.

The Microdot strain gage is unique in that the strain filaments can be individually adjusted by heat treatment after installation in the pressure transducer. In this respect, no other strain gage using a heat treatable wire appears to be adaptable to this type heat treating. All other heat treatable strain gages must, in general, be batch heat treated prior to installation in a pressure transducer and then one must be satisfied with the variations caused by batch heat treating and the installation procedures. The Microdot gage is heat treatable as installed and can be made to match within very close limits the apparent strain curves of each of the other elements in the bridge.

An equally small change in the transducer sensitivity with temperature is accomplished by the addition of a small value (6.5 ohm) platinum resistor in series with the input voltage to the bridge. This temperature sensing resistor is installed in a strain gage housing and is also mounted on the bourdon tube. It, thus, sees the actual operating temperature of the pressure summing device. As the temperature increases, the resistance of this platinum element increases and reduces the voltage applied to the four active arms of the Wheatstone bridge. The resistor value is selected to compensate for the net change in sensitivity caused by the change in modulus of elasticity of the bourdon tube and a change of gage factor of the strain gage. Typically, the change of modulus of elasticity is about 2%/100°F and would increase the sensitivity of

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the transducer, if not otherwise compensated for. The change in gage factor with temperature is a $-1\%/100^\circ\text{F}$ factor. The net result which must be taken care of by the modulus resistor is a $+1\%/100^\circ\text{F}$ factor. For a 120 ohm strain gage bridge, this requires a 6.5 ohm platinum resistor to compensate for it. The small error which does result (less than $.001\%/^\circ\text{F}$) is caused by minor non-linearities in the resistivity of the platinum and the modulus of elasticity and gage factor variations with temperature, and manufacturing tolerances.

It is worthwhile noting that the compensating elements for both zero and sensitivity shifts see precisely the temperature of the pressure sensing bourdon tube. The zero shift compensation elements are the strain gages themselves, and the modulus resistor is affixed integrally to the bourdon tube. The only remaining adjustment resistor is a small (.1 or .2 ohm) wire within the interconnection cavity. This wire is made of the same nickel-chrome material as the strain gage, it is used for achieving residual unbalance, and has a nominal zero PPM resistivity curve. Any differential temperatures between it and the bourdon tube cause only minor errors since it is effectively insensitive to temperature.

Figure 72 is an electrical schematic of the Microdot unit. The circuit shows a means of simultaneous monitoring of the temperature seen by the bourdon tube while measuring pressure. The circuit will measure the voltage across the platinum element (modulus resistor) which is used to compensate for sensitivity changes. Shunt calibration will be possible between EPs. The transducer is provided with two separate cables.

Figure 73 is a rectangular coordinate representation of equation $PV = MRT$. There may be an inherent unique advantage to sealing the reference pressure inside the bourdon tube for NERVA application. Let us assume that a gas is sealed inside a bourdon tube at some given pressure, and a greater pressure is applied outside the bourdon tube. As the outside pressure is increased, the volume of gas inside the tube decreases as indicated by the P-V plot. In a cryogenic environment, there is a further decrease in gas volume inside the tube. But in the presence of gamma heating and/or a high radiant temperature effect the change due to the cryogenic temperature could be off-set. In the figure this is indicated by the temperature ordinate. It is therefore possible that this unit can be built to be self-temperature compensating.

FOR MEASUREMENT OF TEMPERATURE AT TRANSDUCER,
 MEASURE VOLTAGE DROP ACROSS R_M , BETWEEN (+) INPUT LEAD A
 AND (-) OUTPUT LEAD C. CALIBRATION CHART PROVIDED WITH TRANSDUCER.

FOR SHUNT CALIBRATION USE LEADS B AND F.

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Figure 72. Electrical Schematic Open Case Microdot

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P = CORE GAS PRESSURE
 T = CORE GAS TEMPERATURE
 V = VOLUME OF COMPLETELY SEALED SENSING DEVICE
 t = WALL TEMPERATURE OF SENSING DEVICE
 t' = INTERNAL GAS TEMPERATURE OF SENSING DEVICE IF GAS FILLED
 K = CONSTANT

$$PV = MRT$$

or

$$P = K \frac{T}{V(t)}$$

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Figure 73. Rectangular Coordinate Representation of Equation $PV = MRT$ or $P = k \frac{T}{V(t)}$

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2.5 Evaluation of Satham Thin Film Unit

Figure 74 shows the Satham unit. The diaphragm is type 410 stainless steel and a ceramic film (alumina oxide) is deposited onto the diaphragm in order to provide electrical insulation for the bridge elements. Four strain gages "legs" are vacuum deposited on the insulator and are electrically connected into a full bridge circuit by vacuum deposited interconnecting leads. The strain gage material is reported to be a special developed alloy which exhibits the excellent stability, gage factor, and resistance characteristics required for strain gage transducers.

Since the Satham thin film strain gage is bonded directly to the inside surface of the flush diaphragm, it has good thermal conducting paths to the exterior surfaces of the transducer. The internal mass is negligible and the point with the highest calculated internal temperature is 728 °R at 4 watts/gram. It is possible that this unit can be further decreased in size without sacrificing accuracy. Figure 75 shows the WANL unit and also a smaller size which is 10% accurate. Minimizing size is not warranted at this time until a satisfactory test has been completed to determine the integrity of the ceramic bonding material and its insulation resistance properties during reactor operations.

Figure 76 is a plot of the average of three data cycles for each temperature indicated.

Figure 77 is a tabulation which presents the WANL evaluation data versus that done by Satham. Generally, this data shows excellent agreement.

3.0 RADIATION EFFECTS TESTING PROGRAM

3.1 NRX-A6 Internal Evaluation Units

As mentioned previously there are two Wiancko units, one above the shield and one below internal to NRX-A6 vessel. Also above the shield, there will be one Satham unit. These transducers will be cooled by the reactor coolant and will monitor the reactor pressure at their specific location. A post-irradiation examination will be performed on these units.

HEAT GENERATION RATE IS 4 WATTS/GRAM
HYDROGEN COOLANT IS 247°R

CROSS SECTIONAL VIEW

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Figure 74. Estimated Internal Temperature During Irradiation Testing and Internal Assembly Details.
Statham Thin Film Pressure Transducer

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Figure 75. Statham Thin Film Unit

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Figure 76. Thin Film Statham Pressure Transducer Non-Nuclear Performance

DESCRIPTION	SERIAL NO. 31						SERIAL NO. 44						SPEC. LIMITS
	AMB T		400°F		-320°F		AMB T		400°F		-320°F		
	<u>W</u>	S	<u>W</u>	S	<u>W</u>	S	<u>W</u>	S	<u>W</u>	S	<u>W</u>	S	
LINEARITY AND HYSTERESIS % F. R.	.33	.20	.20	.13	.28	.53	.18		.18	.19	.18	.21	1.5
SENSITIVITY M. V. D. C.	28.75	28.84	30.26	30.36	27.05	27.23	30.06	30.10	31.59	31.62	27.98	27.98	
RESIDUAL UNBALANCE % F. R.	.84	.71	.43	1.71	3.70	1.76	.07	1.22	4.78	1.08	1.75	1.60	4
REPEATABILITY % F. R.	.10 .03	.02	.07		.04		.07 .03	.05	.06		.04		.20
THERMAL ZERO SHIFT % F. R./°F			.0034	.0048	.0072	.0060			.0153	.0036	.0038	.0068	.01
THERMAL SENSITIVITY SHIFT % F. R./°F			.0160	.0150	.0149	.0140			.0159	.0168	.0169	.0178	.01

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Figure 77. WANL Evaluation Data Versus Statham

3.2 PBRF Evaluation Test

Two Microdot units and two Statham units are planned to be purchased for this test. The transducers in the capsule will be cooled by helium gas with a capsule inlet temperature and flow controlled to provide a specific temperature at the transducer location. The pressure stimulus is controlled, and precisely known. Also under experiment control is the radiation exposure by capsule insertion. Therefore, a complete design and radiation effects evaluation analysis should be accomplished.

3.3 Future Side-by-Side Test

A design was accomplished for NRX testing as shown by Figures 78, 79 and 80. This capsule would have been placed at a 4 watts/gram region on the outside of the vessel. This type test can be accomplished on some future reactor; and is needed since the PBRF test and preparation time requires about 12 months.

3.4 Problem Areas

The most significant problem area most recently experienced but constantly in this type development picture is the cost of the transducers. These Wiancko development units cost \$7000 each. The manufacturer was to deliver three units in August of 1966; we actually received the third unit in January of 1967. Wiancko claims they spent a total of \$39,000 (or a loss of \$18,000) and they are willing to submit their books to a government audit.

These costs represent one problem area. Means must be found for either proper funding or new designs that are less expensive to manufacture.

The other problem area is strain gages. In an irradiation test at PBRF, Microdot weldable strain gages exhibited a permanent zero shift. The reason for this apparent shift must be determined, or the design previously described cannot be used for accurate pressure measurements.

4.0 FUTURE DEVELOPMENT PLANS

The force summing devices represented by the three transducer types discussed for the NRX-A6 and PBRF evaluation tests should provide sufficient radiation effects analyses

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Figure 78. Transducer Fixture for Side by Side Test

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Figure 79. NRX-A6 Side-By-Side Test

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Figure 80. Side-By-Side Qualification Test of Pressure Transducers

to determine the future accuracy development efforts. In each instance, if the device proves (radiation) successful, it will be possible to simultaneously monitor the temperature effects in order to provide a circuit feedback signal as a means for future accuracy improvement of the pressure measuring system.

The WANL open case concept presents some interesting possibilities for other future developments. For example, Figure 81 shows schematically a method of using an elliptical shaped tube with bondable strain gages. Since pressure will be measured outside of the tube, and the reference pressure sealed internally, the tube therefore provides a hermetically sealed capsule for the strain gages. The strain gages are bonded, or vacuum deposited to the inside of the elliptical halves of the tube. The tube can then be welded shut. The strain gage is terminated in a header and connected to a metal sheath cable. We actually built this unit. To make it convenient, pressure was applied to the inside of the assembly through an 0.040 tube, silver soldered to the strain gage section. Two rosettes were applied to the opposite flat exterior surfaces. Figure 82 is a photograph of one of the units built and tested at WANL. The upper view shows a rectangular outline which measures 0.25 x 0.75 inches. The range of this unit is 30 psia.

The smallness of this unit is only limited by the ability to assembly the strain gages.

Figure 83 shows another open case concept in which the geometry of the unit lends itself to a greater displacement than the previous unit. This concept has not been built as yet.

Considerable combined environmental and radiation effects testing is required for developing transducers for design verification test and continued uninterrupted effort is required over a period of at least two to three years before reactor grade hardware is accomplished.

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Figure 81. WANL Strain Gage/Bourdon Tube Pressure Transducer Concept

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Figure 82. Strain Gage/Bourdon Tube Pressure Transducer Concept

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Figure 83. WANL LVDT/Bourdon Tube, Pressure Transducer Concept

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SECTION IV

CORE THERMOCOUPLES

1.0 INTRODUCTION

Thermocouples in the NRX-A series of reactors are presently installed at Stations 8, 20, 26 and 32. Those at Station 26 are used both for control and diagnostic purposes. The remaining stations are used for diagnostic data. The thermocouples at Station 8 are relatively simple, sheathed chromel-alumel couples. At Station 20 in the first refractory metal thermocouples are used. These consist of a tungsten-tungsten 26 percent rhenium thermocouple, insulated with BeO and sheathed in molybdenum. This same configuration represented in Figure 84 is also used at Stations 26 and 32 except that the molybdenum sheath has a vapor deposited tungsten coating to protect the molybdenum from direct with the graphite. This protection is required to avoid eutectic melting of the molybdenum with carbon. The Station 20 thermocouple has been qualified to 3660°R for NERVA applications and has been used at that station in NRX-A4 and NRX-A5. Further applications in NRX-A6 and XE-1 and 2 are planned. The Stations 26 and 32 thermocouples are qualified to 4000°R and have been used in NRX-A4 and NRX-A5, for both control and diagnostic purposes. The reliability of these thermocouples during reactor testing has been quite good with only a few failures, which appear random in nature, having occurred in each test.

Prior to reactor testing however, several problems exist with these presently qualified designs which have been responsible for a high rejection rate during manufacture and pre-installation testing. Cracks and contamination in the sheath are the principle problems. The cracks are usually located by a preliminary leak test however delays occur when the rejection rate gets above a 10 or 15 percent level. The vendor replaces the defective tubes but four to six weeks are lost. The contamination problem is somewhat less easily recognized. The small diameter and long length of the molybdenum tube makes it difficult to determine if contamination is present on the I D of the tube. It is also very difficult to effectively clean the tube.

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Figure 84. 978D270H03 - Core Element Thermocouple

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We have spent considerable time and effort during the past year on developing methods of removing contamination from the I D of the sheath and to find sheaths fabricated by different processes which will be more contamination free. These efforts have not been completely successful although considerable progress has been made.

In addition to the problems of contaminated sheaths, contaminated insulators have been received from time to time. These insulators cannot be visually differentiated from uncontaminated ones and the only solution to this problem is careful handling of materials during manufacture to avoid introduction of contamination. A more detailed discussion of this problem will be included in the presentation on our insulator development work.

It has been found that moisture in the insulators can also produce undesirable effects however it is readily removed by heating the insulator to temperatures in the vicinity of 3000°R before assembling the thermocouple. Dry box assembly techniques can minimize the chance of moisture being reabsorbed by the dried out insulators. Organic or metallic impurities however are not so easily removed. We have prepared an insulator specification requiring relatively stringent control of material and processes to assure that the purity of the finished product is maintained. Insulators furnished to this specification or with relatively minor deviations, identified before hand, have proved to be orders of magnitude superior to the materials previously being obtained. With these improvements possible, it is likely that the present qualification level of the 978D270 thermocouple designs can be raised by 200 to 300°R.

It is highly desirable for both diagnostic and control purposes to measure the core temperature at Station 45 with a high degree of accuracy and reliability. No NRX reactor run to date has had this measurement because of the unavailability of a qualified design thermocouple. The prime candidate design for this application is part number 928F613 H01 and is shown in Figure 85. This design is similar to the 978D270 except that the sheath is tungsten 25 percent rhenium instead of molybdenum. In this design, a floating plug junction has been used instead of the grounded plug since the expansion and contraction problems are more severe due to higher temperatures and the longer hot zones. This design has been tested a number of times but has not yet been qualified for 4600°R service for one hour.

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Figure 85. 928F613 H01 - Core Element Thermocouple

The testing performed to date has indicated the advisability of incorporating several minor modifications which appear beneficial in improving the life of the thermocouple. Primarily, increasing clearances between the various materials to reduce the possibility of binding between components during temperature transients has proven to be most beneficial. Most of our failures or problems to date have occurred during heat up or cool down when mechanical stress results from differential expansion and contraction. The overall effect of these modifications is still under study and no finalized design has been issued.

One of our earliest attempts at qualification testing of the 928F613 is shown in Figure 86. This test was terminated at the end of fifteen minutes at 4600°R because of furnace problems. As can be seen, the errors averaged about 100°R low when compared with the optical pyrometer. This is relatively good performance at the temperature levels of this test. Post operative X-ray inspection revealed that the sheath had separated on this thermocouple about 2 inches from the tip. Figure 87 shows this thermocouple with the element ground away to reveal the crack. The crack shown by the arrow was the one which appeared on the X-ray. The two other cracks visible in this photo were not present on the X-ray and occurred during the grinding operation because of the brittleness of the recrystallized sheath materials. The X-ray also revealed that one wire was broken. The cause of this was not apparent at the time and therefore the next test was scheduled as a duplicate effort to determine if we had a random failure or a design problem. That test proved to be somewhat erratic and also resulted in a broken sheath. This thermocouple did not perform satisfactorily and appeared to have opened up during the test as is evidenced by the curve shown in Figure 88 where the thermocouple appeared to read high. This type of performance has been observed on several occasions where it was definitely established that the circuit was open. One possible explanation is that some capacitive charging takes place when a wire breaks and causes the apparent increase in output. This type of effect is readily identifiable on the original strip chart record from which this data was reduced.

Figure 86. Station 45 Thermocouple Tested in Hydrogen at 600 PSIG

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Figure 87. 928F613 Thermocouple Serial 31133 After Test

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Figure 88. Station 45 Thermocouple Tested in Hydrogen at 600 PSIG

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Since the next test of a 928F613 thermocouple had already been assembled it was decided to run that unit despite the second sheath failure. The performance of this thermocouple is shown in Figure 89. This thermocouple performed marginally through the first cycle and failed by opening up during cooldown at about 1600°R. Careful post operative inspection of this unit revealed that the sheath had broken about 2 inches from the tip. Measurement of the sheath diameter indicated that it had grown about .005 inches in the area around the break. The wires had grown by about 10 percent of their diameter. Checking dimensions on the previous two failures, was then initiated and the results proved to be comparable. This dimensional change appears to be the result of carbiding of the tungsten. Tungsten carbide is formed at an increasingly rapid rate as the temperature increases and probably indicates a hot spot slightly behind the junction since the most growth seems to occur about two inches back.

In order to investigate this problem more thoroughly, the next test of this basic design was run as a development test in helium with the clearance between the element and thermocouple increased to about .006 inch on the diameter. It was also necessary to run this unit at Station 39 because of the short length of the sheath which was being reused from a previous test. This thermocouple operated through four 15 minute cycles at about 4700°R and can be seen in Figure 90. The thermocouple designated, Z-23, was the short 928F613 thermocouple. As can be seen the Z-23 thermocouple operated well with the maximum error occurring during the second cycle. The other thermocouple Z-13 was an experimental thermocouple built to evaluate the performance of several new materials. As can be seen, its performance was not as consistent as the 928F613 design.

X-ray of the test piece assembly after this test indicated a sheath break 3-1/2 inches from the tip and a wire broken 2-1/2 inches from the tip on the 928F613 thermocouple. The condition of the insulators indicates that this break had probably occurred during the test since there was some evidence of carbon on the insulators although they were not severely degraded.

The next qualification test was performed with a slightly modified design which included a tantalum floating plug and more clearance between wires and insulators. This unit

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Figure 89. Second Test of Station 45 Thermocouples Tested in Hydrogen at 600 PSIG

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Figure 90. Station 39 Thermocouples Test in Helium at 600 PSIG

was run at 4600°R and Station 39 since the sheath was short. This sheath was also being reused from a previous test, having first been turned around so that the junction end would not have been previously carbided and would be similar to a new sheath metallurgically. This unit performed relatively well during four 15 minute cycles in hydrogen as can be seen in Figure 91. This test was within the limits of qualification except that the hot zone was slightly shorter than normal because of the short sheath. The post test inspection showed no wire breakage although there is an indication of a circumferential crack in the sheath on the X-ray. This crack is not separated which indicates that it probably occurred after the unit was cold otherwise, the crack would have opened up from differential expansion of the materials. This crack could have occurred during post operative handling. Several more similar cracks occurred on this thermocouple during removal from the element.

The most recent test of this design was performed at Station 45 in hydrogen and operated well into the third 15 minute cycle. It failed during the third cycle and it is believed that the failure was caused by expansion of the wires in the insulators. The clearances on this unit were slightly less than on the preceeding unit and could account for the difference. The thermocouple was working up to the point of failure.

While the tests performed to date at 4600°R have mostly resulted in failure of the thermocouple to complete the total time intended, these failures have shed a considerable amount of light on the problems causing these failures. The most significant information which has developed is that the clearances both axially and radially which are presently satisfactory in the 4000°R qualified designs are inadequate at 4600°R by a considerable margin. While exact minimums are not yet proven by irrefutable test data, it appears that wires must have clearances of approximately 25 percent of their diameter in the BeO insulators. The BeO should have 10 to 15 percent of the insulator OD as clearance to the ID of the sheath and the sheath approximately 10 percent of its OD to the element hole. Carbiding appears to be the principle cause of degradation. Means to reduce this effect are not readily adaptable to the present design. The 928F613 design with minor modifications does appear to be capable of qualification of 4600°R for one hour. The prospects for higher qualification of that design are poor.

Figure 91. Station 39 Thermocouple Tested in Hydrogen

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As part of the development of a qualified design for 4600°R we have investigated the possible use of vapor deposited tungsten 25 percent rhenium tube with the OD phased out to pure tungsten. One unit completed 55 minutes at 4600°R before failing when temperature was raised. Several others were tested however they each failed when the furnace temperature exceeded 4700°R. In two instances, the higher temperature was reached to achieve the prime objective of the test. In the third instance, the furnace exceeded the planned level unintentionally. Further testing with this sheath material will be performed since the results below 4700°R were sufficiently good to warrant additional work.

One basic problem which we believe has contributed to our wire failures although it cannot be classed as the main problem is the very brittle nature of the tungsten and tungsten 26 percent rhenium after exposure to 4600°R for a short period. The wire failure rate has been reduced by redesigning the floating plug junction slightly to eliminate any bend in the wires where they enter the junction plug. Several redesigned plugs have been used successfully with slightly different configurations. The objective is to duplicate in the plug the exact spacing between wires which results from the insulator web. This keeps the wires from bending at the junction. Testing of this plug configuration to date has been limited, however, the first few tests looked good with no wire breakage occurring in several tests. This solution does not eliminate the cause of the problem but only reduces the effect. It will be necessary to devise methods of minimizing or eliminating embrittlement to achieve long term reliability of thermocouples such as would be required on a space vehicle.

2.0 DEVELOPMENT TESTING

In addition to the efforts to qualify thermocouple designs for core installation, a development program is being pursued to improve the accuracy and reliability of present designs and to evolve new designs capable of qualification at higher temperatures and/or for longer times. The most promising design tested thus far is a dual probe in which only one thermoelement is contained in each sheath. This probe must be used in pairs, with the two thermoelements in two adjacent or closely located holes in the element. The thermoelements

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are grounded at the hot tip and the thermocouple junction is formed by the graphite element itself. A typical probe is shown in Figure 92. In this probe the thermoelement is a tungsten or tungsten 26 percent rhenium thermocouple wire having a diameter of from .025 to .040 inch. The insulators are single hote BeO with about .015 inch wall. The sheath is refractory metal such as tungsten or tungsten coated rhenium. The thermoelement is grounded to the sheath at the welded closure end. Space is provided to allow for the greater longitudinal expansion of BeO.

Four such probes have been tested to date with generally good results. Figure 93 shows the time versus temperature performance of the first dual probe tested. This test was run at 4400°R nominal level with a planned excursion to 4800°R near the end. As can be seen, the correlation during steady state conditions was good. There is some lag between the test thermocouple and the optical during transient conditions such as heat up. This is normal for the type system being employed in the furnace since heat is transferred from the heater element to the test piece primarily through radiation. This radiated heat must then be conducted through the element wall to the thermocouple. In addition, coolant flow is varying as the components heat up causing further instability and gradients. Under these conditions, the first two or three minutes tend to be somewhat irregular on all tests. Once flow and power level are stabilized, the test piece reaches on equilibrium condition as shown on the flat portions of the slide.

The second dual probe was tested at the same 4400°R nominal level and performed quite well also as can be seen in Figure 94. In this unit, the sheath material was different from the first unit tested. The dashed line at the end indicates failure of the dual probe during an attempt to reach 4700°R. This attempt proved that the thermocouple was not shunting and was capable of following a temperature increase. The failure was probably caused by the inability of the unprotected vapor deposited tungsten 26 percent rhenium sheath to withstand the higher temperature and carbon environment.

Post test metallography pinpointed the cause of failure as shown in Figure 95. Note the apparent melt and bridging between the tungsten-rhenium wire, BeO and tungsten-rhenium sheath. Also, there is heavy carbide present. This element was broken probably from the stress

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Figure 92. Sheathed Thermoelement for Dual Probe

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Figure 93. Dual Element Thermocouple Tested in Hydrogen at 600 PSIG

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Figure 94. Station 39 Dual Element Thermocouple S/N R-14 Tested in Hydrogen at 600 PSIG

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Figure 95. Transverse Section Tip of Tungsten 26% Rhenium Leg of Thermocouple R-14 After Test

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of differential longitudinal expansion after the bridges had formed. We believe that carbon penetration was a significant factor in this failure although there is insufficient data to state whether the carbon arrived through a crack or whether it was solid state diffusion. Either case could account for these conditions. Cracks are definitely evident in the sheath but whether they were the cause or effect cannot be stated with certainty. Of interest also on this test is Figure 96 in which a similar section was taken of the tungsten thermoelement in the same area. Note the severe cracking of the tungsten wire, heavy carbiding of the sheath and cracking of the ID of the sheath. Despite these indications, this thermoelement was electrically continuous. This figure is one of the most severe examples of thermoelement cracking which we have observed. The presence of cracks in the thermoelements is not new and is an area which must be studied to improve performance and life of thermoelements at high temperature for PFRT verification tests. Figure 97 is the same thermoelement sectioned two inches from the tip. Comparing the two slides reveals that the cracking is much less pronounced in this figure, with only one major crack in evidence. Note the carbide ring with the smaller cracks and also that the carbide is deeper along the major crack, indicating that that crack was present early in the period of carbide formation.

The next dual probe test was performed in helium with tantalum sheathed thermoelements. The tips of the thermoelements were not potted into the element to evaluate the effect of this change. The test was run at 4600°R nominal as shown in Figure 98. The accuracy was not as good as on previous tests, however the probe did survive the hour at temperature. Two cycles of thirty minutes duration were run on this unit to reduce the chances of failure from cycling.

The most recent test performed on this development thermocouple is shown in Figure 99. This test was intended to evaluate the potential accuracy at intermediate temperatures from 2000°R to 4600°R during heatup to establish that this configuration would be useable at intermediate power levels as well as near full power. As can be seen, the correlation was very good. Because of a misunderstanding of instructions the tips of the elements were not

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Figure 96. Transverse Section - Tip of Tungsten Leg of Thermocouple R-14 After Test

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Figure 97. Transverse Section - Tungsten Thermoelement of R-14, Two Inches From Tip

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Figure 98. Station 45 Thermocouples Tested in Hydrogen at 600 PSIG

Figure 99. Station 45 Thermocouples Tested in Hydrogen at 600 PSIG

potted in and we believe this accounts for the failure of the probe to stabilize on the 4600°R hold on the first cycle. This type of performance is characteristic of a high resistance junction. The test piece was removed from the furnace and X-rayed after the first cycle to determine if one of the thermoelements had open circuited. The X-rays showed no defects as compared with pre-test X-rays. The second and third cycles were then performed and the results were quite good as shown in Figure 100. This figure is a plot of deviations from the optical pyrometer readings. The dashed lines represent $\pm 100^\circ\text{R}$ deviation and bracket all but one point which was the point encountered during the first cycle as discussed previously. This test was not a complete success, however, since one thermoelement opened up after the third cycle and the test was terminated. The exact nature of this failure is not yet known since post operative examination is not yet complete. Further development of this type probe is planned to determine its full potential for possible reactor use.

Another new design which has been tested is one originated by G.E.-NMPO under contract to WANL. Because of their experience on the ANP project and its similarity to NERVA, a contract was awarded to design and produce three thermocouples for development test at 5000°R. The thermocouples which were designed appeared in cross section as shown in Figure 101 and consisted of an extruded tungsten sheath, a .003 thick tantalum shield inside the sheath, hafnia insulators and stranded tungsten/tungsten 26 percent rhenium thermoelements. Three thermocouples were delivered and tested at WANL. The first test was performed in helium to evaluate the effect of temperature without risking hydriding of the tantalum which might confuse the results.

This test is shown in Figure 102. As can be seen, the thermocouple appeared to shunt out at 4000°R and was essentially insensitive to temperature above that level. The second thermocouple shown in this figure was a WANL built BeO insulated two-wire thermocouple installed as a double check on the optical pyrometer. As can be seen, it correlated comparatively well with the optical readings.

After the test, metallographic inspection was performed to evaluate the condition of the materials in the G.E. thermocouple. Figure 103 is a transverse section through the tip

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Figure 100. Deviation Curve for Station 45 Thermocouples Tested in Hydrogen at 600 PSIG

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Figure 101. Transverse Section - HfO_2 Insulated Thermocouple F-1 Cool End - After Test

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Figure 102. Station 39 Thermocouples G.E. HF-1 and Z-12 Tested in Helium at 600 PSIG

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Figure 103. Transverse Section - Top of Thermocouple F-1 After Test

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of the thermocouple. The tungsten sheath was severely carbided and the stranded wires appeared to begin to melt together. Since this section was through the junction, it is possible that junction welding may have caused the change in the wires, although, later test results showed similar wire changes in areas remote from the junction weld.

The deterioration of the sheath itself is shown in better detail in Figure 104. Platelets of carbide are clearly visible. There is also an unidentified coating on the inside diameter of the tungsten tube. The tantalum shield is broken in several places. This may have occurred during metallography since the tantalum was completely carbided and thus was very brittle.

Post test disassembly of this thermocouple revealed that the insulators were heavily discolored near the tip as shown in Figure 105. This discoloration was analyzed by spark gap analysis techniques and showed a high carbon content. Note also the bright condition of the tantalum. Figure 106 is the same thermocouple in the cooler end. As can be seen, the hafnia is clean and uncontaminated. This was verified by spark gap analysis in addition to the visual observations. The tantalum here is dark which is its normal coloration when not carbided.

The next test with this design was performed in hydrogen and its performance is illustrated in Figure 107. The thermocouple again shunted out although at a slightly higher level. The WANL thermocouple failed from over temperature during the first cycle. Post test X-rays of the G.E. unit showed that the thermocouple junction was displaced from the remainder of the thermocouple by about one inch. The sheath was broken about 3/16 inches from the tip. This break was confirmed visually and is shown in Figure 108. Disassembly of the thermocouple revealed that the tantalum shield had turned gold in color indicating carbiding. The insulators on the hot end were black in color and were conductive when checked with an ohmmeter. This accounts for continuity of the thermocouple output even though the junction was separated from the wires. A section was taken two inches from the tip and is shown in Figure 109. The sheath was heavily distorted and cracked as well as being carbided. The hafnia was spongy in texture and there was an apparent reaction between the tantalum and the hafnia. The tungsten-rhenium thermoelement was melted and pooled to one side and the tungsten thermoelement strands had begun to sinter together as shown more clearly in Figure 110.

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Figure 104. Transverse Section - Tip of Thermocouple F-1 Sheath After Test

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Figure 105. Post Test Condition of Tip of Thermocouple F-1

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Figure 106. Post Test Condition of Mid Section of Thermocouple F-1

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Figure 107. Station 39 Thermocouple Tested in Hydrogen at 600 PSIG

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Figure 108. Broken Thermocouple Sheath

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Figure 109. Transverse Section - Tip of Thermocouple F-2 After Test

Figure 110. Enlarged View of Transverse Section - Tip of Thermocouple F-2 After Test

The third unit was run the next day following and performed in a similar manner. On this unit, the thermocouple appeared to shunt out at about 4500°R as shown in Figure 111. This thermocouple also lost its junction as was later determined by X-ray. The insulators were again discolored. Metallographic sectioning again revealed that the tungsten wires began to sinter together, the tungsten-rhenium wires had melted and the hafnia had reacted with the tantalum. The distortion and cracking of the sheath was not as severe as on the previous unit. Carbiding was heavy. The WANL thermocouple installed in this test was not originally intended for service above 4700°R and failed during the first cycle when the temperature was raised to 5000°R.

In summary, the hafnia insulated thermocouples designed and furnished by G.E.-NMPO did not operate in a manner which would indicate full qualification capability of that design. The failures of two junctions, the wires melting and the reaction of the hafnia with carbon and/or tantalum are problems which require a considerable amount of work and study. These tests did however, provide information for future development for higher temperatures. The HfO_2 did not melt as BeO would have at the temperatures of these tests. The tungsten sheaths need improvement to eliminate the distortion and cracking problems. The tantalum inner shield may have provided some protection although this is questionable. The stranded wires probably were a disadvantage. Since they began to sinter together they have no advantage over solid conductors and have the disadvantage of less cross section resulting in higher conductor resistance and more surface area allowing more rapid carbide formation. This further emphasizes the necessity for shielding the thermoelements from carbon. Theoretically, the tantalum shield provides some measure of protection since its close lattice structure is more resistant to solid state diffusion of carbon than is tungsten. It is possible perhaps even likely that the carbon penetrated the sheaths through cracks in which case the tantalum would offer no significant protection. Metallography could not evaluate the tantalum because it disintegrated in the mounting and polishing process.

Development tests were also conducted on two molybdenum sheathed thermocouples having compacted BeO in the hot end. These thermocouples were supplied by the West Lynn, Massachusetts, Instrument Department of General Electric. These thermocouples performed

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Figure 111. Station 39 Thermocouples Tested in Hydrogen at 600 PSIG

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moderately well at 4000°R as shown in Figure 112. They appeared to fall off in output with time and did not respond very well to increased temperature near the end of the test. The material was very brittle and numerous cracks were detected by X-ray. There was also broken wire in one unit. However this may have been caused by disassembly and cannot definitely be attributed to the test. Metallography on these units is not yet complete but first indications are that severe carbiding took place. The second unit in that test was thermocouple Z-4 which was a vitrified BeO insulated two-wire thermocouple with a molybdenum rhenium alloy sheath. Its output was more typical of the accuracy presently being obtained with high quality development thermocouples at these temperatures. This unit failed after the third cycle. The cause is not definitely established but appears to be eutectic melting of the molybdenum-rhenium sheath on its OD. A complete evaluation of the compacted units is not presently available. However, they did not perform as well as our present designs and appeared to suffer more deterioration than presently qualified 978D270 thermocouples. It is possible that the application of a vapor deposited tungsten coating similar to that on the 978D270, HO₂ thermocouple would be beneficial to the compacted thermocouple design.

Another new thermocouple design which has had one furnace test to date was a vapor deposited thermocouple formed by depositing HfO₂ on a tungsten 26 percent rhenium wire about .010 thick, and then vapor depositing tungsten on top of the HfO₂ to form a coaxial thermocouple. This unit was inserted in a vapor deposited tungsten tube with BeO insulation to isolate the thermocouple electrically from the element. Performance was poor as a thermocouple, with the indication that one element was grounded to the sheath when at temperature. The mechanism that caused this problem has not been identified as yet. The most useful indication was that the co-deposited coaxial thermocouple itself appeared intact by post test X-ray except in an area where the outer sheath and BeO had also failed. There was no indication that the expansion and contraction of the vapor deposited materials caused any problems. Further testing is planned on complete thermocouples manufactured by the vapor deposition technique. San Fernando Labs is performing this work for WANL. The first real test is inconclusive. However, the failure cannot be looked upon as a total loss since some evidence was obtained indicating the feasibility of this idea.

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Figure 112. Station 32 Thermocouples Tested in Hydrogen at 600 PSIG

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3.0 DEVELOPMENT TESTING - SHEATHS

Various sheath materials are being evaluated in the High Temperature Thermocouple Qualification Test Furnace, usually as a secondary objective of the test program. In general the sheaths are assembled into thermocouples similar to Figure 113. This standard development test thermocouple has proved quite useful and is less difficult to assemble than a grounded junction type. The intermediate temperature insulators are usually MgO or occasionally Al_2O_3 . High temperature insulators tested thus far have been BeO, HfO_2 or high purity MgO. Sheathed leads are usually .090 inch OD stainless sheaths with compacted MgO insulation. The junction shown in this figure is a floating plug type. We have made junctions of this type from various refractory materials including tungsten, tungsten 26 percent rhenium, tantalum, moly-rhenium and several others. Figure 114 shows an actual photo of a typical floating plug. Our experience with moly-rhenium floating plugs is inconclusive. Its fabrication is easiest since the material is ductile at room temperature and can withstand moderate swaging to provide a good mechanical junction. Performance at elevated temperature has been erratic with apparent melting occurring as low as 4000°R in some instances while in others it appears to have survived temperatures as high as 4400°R. The penetration of carbon to the inside of the sheath appears to be the most significant factor in the failure of moly-rhenium junctions and we have discontinued use of them for the present.

Thermocouples built to the standard development thermocouple design are assembled in most instances in a dry atmosphere in the glove box shown in Figure 115. On an average day, this box and its dryer maintains a moisture content of less than 30 ppm as measured by the Beckman Electronic hygrometer which can be seen mounted on top of the box. Final sealing of the assembled unit is usually accomplished by induction brazing in an inert atmosphere. The equipment used is illustrated in Figure 116. With this equipment it is also possible to evaluate and backfill the assembly with an inert gas under a slight positive pressure. Our most common backfill is dry helium at 15 psig. After assembly and sealing, the thermocouples are leak checked and if satisfactory are made available for furnace testing. Most development thermocouples are built to evaluate insulator quality, junction materials or sheath materials

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Figure 113. Standard Development Test Thermocouple-High Temperature.

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Figure 114. Typical Floating Plug Junction

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Figure 115. Glove Box for Assembly of Thermocouples

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Figure 116. Equipment for Induction Brazing

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or sheath materials with the latter being primarily tested in the qualification test furnace since sheaths are not as easily evaluated under simulated furnace conditions. The new sheath materials which we have tested and the temperatures we are attempting to achieve are shown in Figure 117. This chart is not intended to indicate that these levels are achievable on a reliable basis at present. The temperatures which have been achieved are the best results thus far. There may have been other unsuccessful attempts at the same temperature levels. This chart is presented only as an indication of the potential capabilities of the various materials under study.

The best extruded tungsten performance occurred during our Test 1266D2B which was the last test of the G.E. hafnia insulated thermocouples described earlier. That test included four 15 minute cycles at or above 5000° with a maximum of 5070°R observed optically. There were no sheath defects visible on X-ray after the test although some cracking and distortion was found during metallographic examination. That thermocouple performed the best of the three units of its kind tested.

An extruded thoriated tungsten sheath was in a very recent test and operated quite well at the 4600°R test temperature. No attempt was made to run at higher temperature since that was the first test of that particular sheath. Figure 118 is a plot of time versus temperature for that thermocouple and shows the good results obtained on that unit. The sheath showed only a minor indication on X-ray of a possible crack. The element was ground away to remove the thermocouple and no cracks were visible on the approximately half of the visible sheath. Several cracks did occur during removal which is not unusual with these embrittled materials.

Vapor deposited tungsten 25 percent rhenium tube has been tested in several tests including the R-14 dual probe described previously. The basic material has a columnar grain structure as shown in Figure 119. This structure makes the tube somewhat more brittle than wrought tungsten rhenium alloy tube however, the tubing has been useable without severe rate of breakage. The limiting condition on the uncoated tubing is eutectic melting in the presence of carbon. This problem can be reduced by phasing out the rhenium on the surface so that there are two or three thousandths of pure tungsten on the outer surface of the sheath. Tubes of that composition were used in the dual probe R-15 which operated for one hour at 4600°R with several minutes at 4870°R.

SHEATH DEVELOPMENT CANDIDATES

<u>MATERIAL</u>	<u>MAXIMUM ANTICIPATED TEMPERATURE</u>	<u>HIGHEST ACHIEVED TEMPERATURE</u>
EXTRUDED TUNGSTEN	5000°R	5070°R
EXTRUDED THORIATED TUNGSTEN	5000°R	4600°R
VAPOR DEPOSITED TUNGSTEN 25% RHENIUM	4600°R	4500°R
VAPOR DEPOSITED TUNGSTEN 25% RHENIUM PHASED OUT TO TUNGSTEN	4800°R	4870°R*
WROUGHT MOLYBDENUM RHENIUM (50/50)	4000°R	SHEATHS FAILED
VAPOR DEPOSITED MOLYBDENUM	4000°R	4200°R

* LESS THAN 5 MINUTES

Figure 117. Potential Capabilities of Various Materials

Figure 118. Station 45 Thermocouple Tested in Hydrogen at 600 PSIG

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Figure 119. Transverse Section Typical Vapor Deposited Tungsten 25% Rhenium Tube. Wall 0.010 Inch

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Wrought molybdenum rhenium has been tested as a possible replacement for pure wrought molybdenum which has been used previously but with which there exists a contamination problem. No successful tests have yet been achieved at the 4000°R level with these sheaths. In the two tests conducted to date, the sheaths cracked and separated during the test. It is possible that the 4000°R level is too high for an unprotected moly-rhenium sheath. While eutectic melting does not reach catastrophic proportions at this temperature level, it appears that it may be taking place on the surface with resultant sticking of the sheath to the graphite. This is a hypothesis only since the post test analysis on these two units is not yet completed and the actual cause of failure has not been pinpointed. In a further effort to obtain contaminant free molybdenum tube, vapor deposited molybdenum has been obtained. Figure 120 shows a typical section through the vapor deposited tube. The columnar grain structure is similar to that found in the vapor deposited tungsten rhenium tube. The molybdenum tube is about as fragile as the tungsten-rhenium and has had a moderate breakage loss. The best test thus far was one hour at 4200°R in four 15 minute cycles. The sheath did not crack during this test. No analysis of the effects of carbon on the sheath are yet available since this test was only recently performed.

In addition to the sheaths shown earlier on the chart, some testing has been performed on tantalum with vapor deposited tungsten coatings. Catastrophic failures similar to that shown in Figure 121 have caused the .003 thick coating to be disqualified. Several sheaths had been coated .009 thick to determine if this would provide sufficient protection to prevent hydrogen embrittlement. Two tests were conducted, the first being a resounding success with the thermocouple showing no ill effects after twenty minutes exposure to hydrogen and temperature. The second test however, returned to form for tantalum in hydrogen and was not successful although the element was not damaged by the hydride. As a result of this second test, the tungsten coated tantalum sheath has remained as a disqualified candidate.

Sheath development during the past year has progressed significantly. It now appears possible that several sheath materials may be capable of eventual qualification to 4600°R and

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Figure 120. Transverse Section - Vapor Deposited Molybdenum Tube. Wall 0.010 Inch

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Figure 121. Typical Breakout of Hydrided Tantalum

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the ability of a sheath to withstand 5000°R has been demonstrated. While a considerable amount of work remains to be done to be able to achieve these objectives on a reliable basis, the achievement of even one success amid several failures establishes the feasibility of eventually achieving the objective of full PFRT verification.

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SECTION V
INSULATION

1.0 INTRODUCTION

The aim of the WANL continuing development of high temperature thermocouples for the NERVA cores is to increase the present qualification temperature from 4000°R to 4600°R and ultimately to 5000°R. This review covers the progress made on insulation as used in the current thermocouple system. This system, based on a conventional design, consists of a long train of double-bore ceramic insulator segments strung on two thermoelements in a continuous metal sheath which is hermetically sealed.

In the last review we reported that some thermocouple units manufactured by vendors to WANL Drawing 978D270 Revision B had to be rejected due to 6 to 8 percent decrease in loop resistance. This decrease in loop resistance was found to have occurred only with units having coating of vapor deposited tungsten on a molybdenum sheath. The tungsten coating was deposited by the vendor after the units were assembled and sealed, and during application the sealed units were exposed to about 2200°R. Disassembly of the faulty units showed that the insulators were badly discolored, that the loss of loop resistance was due to shunting between the thermoelements caused by conductive layers on the surface of the insulators, and in some instances by bulk conduction of the BeOinsulator segments. A spectrographic analysis of the discolored insulators showed a high concentration of carbon, and further evaluation showed that the source of the carbon was in the BeOinsulation.

This led to an investigation of BeOcontamination at low temperatures of about 2000°R. We know now that the carbon contamination was restricted to several lots of insulators by the National Beryllia Corporation which was then our sole vendor. Since then we have evaluated commercial insulators by Coors Porcelain Company and by American Lava Company. We are now also evaluating commercial insulators by the Brush Beryllium Corporation.

The Brush Beryllium Corporation will also supply us with special non-commercial high purity and very high purity BeOinsulators for our evaluation.

The results of our work on BeO contamination have shown it to be a problem which is applicable to any high temperature insulation in a tight and sealed system of our current

design. In this design the sliding fit between the insulators and the sheath leaves very little room for vaporized products to be carried away. In fact, due to the thermal gradient in the system the vaporized products condense and deposit on the surface of the insulators at the cooler region of the system. As the time at temperature increases the confined space surrounding the insulators becomes saturated with the vaporized products so that they also deposit in the hot regions. When the vaporized products are electrically conductive, conductive paths form on the surface of the insulators and shunt the thermoelements at the terminals of the insulator segments.

Our initial approach to the problem of contamination was to identify these products and the processes which degrade the electrical resistance in the current thermocouple design.

There are two possible major types of contamination in a ceramic. The contamination may be due to extrinsic impurities, to extraneous impurities, or to both. The main difference between the two types is that extrinsic impurities have become an integral part of the ceramic while extraneous impurities are those which are not an integral part of the ceramic.

We have obtained samples of dense commercial insulators of requisite configuration having a nominal end-product purity ranging from 99.0 to 99.8 percent BeO. The impurities in question, therefore, ranged from only about 10,000 ppm to about 2000 ppm and were primarily of the extrinsic type. These extrinsic impurities stem from the residual impurities in the starting material and from impurities picked-up during blending, extrusion, and sintering of the end-product. Most of the extrinsic impurities which exceed about 700 ppm, however, are purposely added by the commercial vendors as sintering aids. Sintering aids are oxides such as MgO, Al_2O_3 , CaO, and SiO_2 which are added in order to obtain insulators having a dense structure with no open pores at lower sintering temperatures.

It should be noted here that most vendors report the extrinsic impurities, which also include the sintering aids, as elements and not as the oxides of the elements. This results in an apparent higher BeO purity value. If, for example, the purity is claimed to be 99.7 percent BeO with 3000 ppm (0.3 percent) magnesium as an elemental impurity, the available BeO is actually only 99.5 percent since for about every 3 parts of magnesium there are 2 parts of oxygen by weight (in MgO the atomic weight of magnesium is 24 and oxygen 16 giving a ratio of 3 to 2). In this example the true composition is 99.5 percent BeO and 0.5 percent MgO.

The extrinsic impurities, in an open system, affect the electrical resistivity only at low temperatures. This is illustrated in Figure 122 where the log of the resistivity versus the reciprocal of the absolute temperature was plotted for a Brush Beryllium Company ceramic with an apparent 99.8 percent BeO purity. The plot shows that with increase in temperature there is a sharp transition at the "knee" from an impurity dependent extrinsic process to an impurity independent intrinsic process. This means that at higher temperatures, from about 2400°R, the resistivity is not affected by the presence of extrinsic impurities. At lower temperatures, however, the extrinsic impurities cause a decrease in resistivity. At 2000°R, for example, the resistivity is approximately 15 times less than that of a theoretically pure sample.

The impurity independent portion of the curve of the Brush sample practically matches the curves reported by Pryor in 1964 and by Foex in 1942 as shown in Figure 123. The curve by Pryor represents the results of four diverse samples, two of which were single crystals of very high purity, and the other two were polycrystalline ceramics of nominal purity.

All commercial BeO insulators contain some extrinsic impurities which are added to obtain an impervious structure. The highest commercial nominal purity is Brush Beryllium Company Thermalox 998 with 99.8 percent BeO and about 0.2 percent MgO as sintering aid. The nominal purity of American Lava Corporation AlSi Mag 754 BeO is 99.5 percent the balance being 0.3 percent MgO and 0.2 percent Al_2O_3 as sintering aids. The nominal purity of Coors Porcelain Company DB995 BeO is also 99.5 percent with similar sintering aids. The above products have impervious structures and assure freedom from extraneous impurities such as carbon and absorbed water. The structures of National Beryllium Corporation commercial BeO insulators, however, are not completely impervious. In fact, National Beryllia K150 with a nominal purity of 99.9 percent BeO has a porosity of 5 to 10 percent in terms of water absorption. National Beryllia K140 with some sintering aids to give a nominal purity from 99.0 to 99.8 percent BeO has nevertheless a porosity of 0.1 to 0.2 percent water absorption. In either case the National Beryllia Corporation BeO insulators are of uncertain purity and all are porous.

Porous ceramics are readily contaminated with extraneous impurities. The source of the carbon, described earlier in this review, in the bulk of National Beryllia insulators was

SPECIFIC RESISTANCE OF BRUSH BeO*

Figure 122. Plot of Electrical Resistivity

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Figure 123. Specific Resistance of BeO

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due to the zyglo solution which was absorbed by the porous insulators during inspection for flaws. Zyglo and similar dye checks having an oil base used for checking the soundness of the insulators are a potential source of carbon contamination.

Another source of impurity is water. Porous ceramics readily absorb water which can be driven off by a low temperature bake. The problem is more critical with adsorbed water. Like all solids the beryllia ceramic seeks to minimize its surface energy. Water moisture by virtue of its lower surface energy is readily adsorbed by the beryllia so as to lower its surface energy. As a result a monolayer of water is strongly bonded to the ceramic. In the case of beryllia temperatures as high as 3000°R are required in order to break this bond and completely drive off this impurity. It is more difficult to break this bond with porous ceramics since a porous structure has a larger surface and a higher surface energy than a highly sintered and impervious structure. The effect of adsorbed water is illustrated in Figure 124 where the resistance of the sample insulators was at its lowest after the first 15 minutes at 2000°R and then increased by 2 and 3 orders of magnitude after a total of 120 minutes. The samples were single length impervious 99.5 percent insulators by Coors in a tight and sealed system. The test was conducted in the low temperature test furnace shown in Figure 125.

In conclusion, I would like to say that we have made a great deal of progress in solving the problem of BeO contamination at 2000°R and lower. We now specify that the insulators be impervious and that they should not be dye checked during final inspection. To eliminate adsorbed water we have been "conditioning" the insulators prior to assembly. One method used is shown in Figure 126 but other methods are being also explored. From this work we have also gained much insight into the properties of commercial BeO insulators and an approach to solving the problem of BeO contamination at temperatures above 2000°R. Although we know that extrinsic impurities such as the sintering aids do not affect the intrinsic resistance of BeO at elevated temperatures in an open system, we are concerned with the side-effects these impurities have in a tight and sealed system of our current thermocouple design.

We have been successful in that we have now three more vendors of higher purity insulators than our original vendor, the National Beryllia Company. We are anticipating some

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Figure 124. Resistance of Samples No. 39 and No. 42 at 2000°R

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Figure 125. Low Temperature Insulation Test Furnace

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Figure 126. Torching of Insulators

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good results with Brush Thermalox 998 having a nominal purity of 99.8 percent BeO and an impervious structure. We are looking forward to experimental samples having a nominal purity of 99.9 percent BeO and 99.8 percent BeO which are also being fabricated for us by the Brush Company. This company is being very helpful in our current investigation of the effect of extrinsic impurities at our goal temperatures in a tight and sealed system.

The literature and post-evaluations by WANL indicate that BeO is the material having the highest electrical resistivity at very high temperatures. Since BeO melts at about 5000°R it is the best candidate material, in terms of electrical resistivity as well as chemical and physical stability, for service to about 4800°R and perhaps 4900°R. For higher temperature goals other materials having higher melting points are being sought and investigated. Candidate materials for higher temperature goals are HfO₂ and ThO₂. They have higher melting points than BeO but in many ways they are not as stable as BeO. HfO₂ and ThO₂ are known to have greater structural defects and are subject to departure from stoichiometry by temperature and atmosphere. The defects explain why the specific resistance values of HfO₂ and ThO₂ are reported to be lower than BeO at elevated temperatures, and it may be necessary to change the thermocouple system design to compensate for the lower specific resistance. More detailed information on the progress made in insulator and sheath development is given in WANL-TME-1549, titled "Thermocouple Insulation Development During Contract Year 1966," and in WANL-TME-1535 (CRD) titled "Thermocouple Sheath Development During Contract Year 1966."

Future work areas in development testing of sheaths, thermoelements, and insulators will cover fabrication, material properties, material compatibility and optimum system design. We will seek and work with vendors having the fabricating facilities and the experience to consistently produce materials and components capable of meeting the requirements of design verification testing. We will study the basic properties of candidate sheath, thermoelement, and insulator materials and the interaction between them in a tight and sealed system at NR and NE temperatures in a hydrogen and carbon environment. From these studies, we will establish an optimized system capable of meeting the requirements at design verification testing.

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SECTION VI

LVDT

1.0 INTRODUCTION

Linear displacement measurements are required within the pressure vessel of the NERVA reactor for the following reasons:

- 1) To determine the magnitude and frequency of radial displacements between the core components.
- 2) To determine the magnitude and frequency of relative displacements between the core and the core support plate.

This information is necessary for verification of reactor design calculations and for the proper evaluation of the structural integrity of the core and its support system.

2.0 REVIEW OF PRESENT DEVELOPMENT STATUS

For the NRX series, the axial displacement and vibration between the core and the core support plate was measured with LVDT's. The radial core displacement was measured by Microdot weldable strain gages mounted across the face of the core lateral support leaf springs.

3.0 PERFORMANCE HISTORY

The performance history of these transducers is detailed in WANL-TME-806.

In the development of second generation NRX reactors and particularly for NRX-A6, the core lateral support system had been redesigned using helical springs instead of the leaf type.

For future reactors it had been suggested that an alternate method be investigated whereby these measurements can be made with six LVDT's mounted in the beryllium reflector evenly spaced around the reactor core to increase the accuracy of the measurement.

To measure axial displacement and vibrations between the core and core support plate, three LVDT's will be mounted on the aluminum core support plate. An analysis of the displacement data from NRX-A6 test runs indicates that the ± 100 mils range of the LVDT's now available is not adequate to measure the relative displacements between the core and reactor

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components. In addition, in future reactors gamma heating at the transducer locations will be approximately 10 watts per gram, due to the single reflector. The fast neutron flux will be up to 10^{15} n/cm²-sec ($E > 1$ Mev).

It was reported in the March 1966 Review Meeting that a program was initiated at that time to develop an improved design for the required LVDT with a range of ± 250 mils (± 0.250 inches).

By means of development specification, drawings, and heat transfer calculations, an improved LVDT design was contracted with Schaevitz Engineering and Crescent-East.

Presented here is a typical computer thermal analysis calculation of the heat transfer characteristics of the improved design. With gaseous hydrogen flowing past the surfaces at 203°R, and an internal heat generation rate of 10 watts per gram, the maximum hot spot indicated will not be more than 749°R in the coil area, and not more than 860°R in the plunger.

It should be noted that the plunger is made of Westinghouse Hyperco, which has a Curie point of 2238°R. The coils are made with silver wire and insulated with a ceramic called "Secon".

4.0 DEVELOPMENT PROGRESS SINCE MARCH 1966

The development progress since last March has been very disappointing. According to the purchase contract, delivery of the units was promised in July 1966. The first unit was received 3-3-67.

There have been consistent delays due to manufacturing problems with these units which have not been typical of commercial grade designs. We have visited with both concerns; and assisted with welding problems and coil winding difficulties.

5.0 RADIATION TEST PROGRAM

When the units are received, complete non-nuclear qualification tests will be performed to evaluate the electrical and mechanical parameters.

A radiation effects test is planned at PBRF. It is planned to monitor the resistance of the coils in order to correlate the gamma heating and temperature effects. The results of this test will determine the future nuclear qualification and development work required.

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6.0 FUTURE PLANS

The future plans depend to a large degree on the results of the next PBRF test and also on the funding made available for Design Test verification.

It was shown that the proposed design was made with materials which should withstand the required environment. If the PBRF test indicates unexpected difficulties, thermocouples should be built into the unit in order to compare the calculated heat transfer values with the actual. Perhaps an open-case approach will be needed for improved internal cooling.

One important feature that this program needs, and which has been more or less taken for granted, is a dependable source of ceramic insulated wire.

After five years of transducer development work, it appears that there is not more than one, or possibly two, NERVA reactor grade qualified ceramic insulated wire suppliers for small coils such as are used in LVDT's and variable reluctance type transducers. Future design verification development efforts also depends on these small companies remaining in business.

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SECTION VII

REFERENCING OF WANL CRYOGENIC TEMPERATURE MEASUREMENTS FOR NRX-A6

1.0 INTRODUCTION

Problems have been encountered in the measurement of cryogenic temperatures for all NRX testing up to and including the NRX-A5 test. Difficulties encountered have resulted from improper grounding techniques, failure of the reference junction controls to operate, improper hookup of the thermocouples, and extremely large data system errors. Attempts have been made to improve the quality of the measurements by more accurate calibration of thermocouples, scheduling of experimental plans designated strictly for the verification of hookup of instrumentation, and the use of teams of individuals specifically assigned the responsibility of determination of the worth of data taken. These attempts have greatly reduced the amount of human error associated with cryogenic thermocouple measurements. Nevertheless, those errors associated with the data system have not been markedly reduced during the NRX test series.

2.0 PROBLEMS ENCOUNTERED WITH TEMPERATURE MEASUREMENTS AS SEEN ON EARLIER NRX TESTS

Errors encountered in cryogenic measurement during NRX testing may be grouped into three principal areas. Each of these will now be discussed.

2.1 Referencing Techniques

Well Referencing - During early NRX tests conducted at Test Cell "A", reference wells were utilized as the sole means for thermocouple referencing. These wells were located in the Flow Control Room (FCR) immediately inside the test cell from the test car. The wells themselves were quite deep and varied only slowly in temperature. A frequent problem was the failure to obtain an actual reading of well temperature before or immediately after the test, resulting in the need to take an educated guess as to what the temperature may have been at the time of the test. Well referencing was abandoned prior to NRX-A2, when it became obvious that sufficient moisture had crept into the wells as to make the majority of the reference thermocouples unreliable.

Pace Reference Boxes - As the number of cryogenic thermocouple measurements increased, it became necessary to insure a more accurate referencing scheme with less disadvantages than the use of reference wells. Consequently, heated reference boxes were purchased from Pace, Incorporated and mounted on the test car. These boxes employ the use of two heated junctions which have an effective electrical output equivalent to an ice-point reference. The Pace boxes were a considerable improvement over the well referencing technique. Essentially, each heated junction block in the Pace boxes was referenced and controlled with an RTT reading the temperature of the blocks. Some interesting effects were observed:

1) As the gamma heating increased, the reference junctions tended to show drift, and the blocks crept upward in temperature, showing changes as high as 22°F (EP-V, NRX-A3).¹ The thermal shift in reference temperature has been shown to result in measurement errors in excess of 10°R.

2) Work by Mr. D. E. Swartz of AGC has shown that some hardening of the Pace boxes seems to occur after considerable gamma heating of these units. For example, whereas the block temperature changed by 22 degrees on NRX-A3, EP-V, the same block exhibited only a 4 degree rise in temperature on NRX-A3, EP-VI. It seems likely, however, that this effect might not be reliable, although it was evident in four previous incidents, resulting from gamma heating on earlier EP's.

3) Investigation was also made of the effect of moving a block temperature controller from the Pace box to a point inside the test cell where radiation would be considerably lower. This was accomplished only once on NRX/EST, to the high temperature block in Pace reference junction box A. Whereas on NRX-A3 this particular block exhibited temperature shifts of up to 16°R, when the controller was moved the net shift was less than 3°R. These results seem to indicate that the temperature shifts observed were because of the heating of the controllers rather than the blocks. By movement of all controllers into the test cell a more stable means of referencing might be obtained. However, it should be emphasized that only an extremely small amount of data have been accumulated on this phenomenon (one single case

¹ REON Technical Memorandum No. RN-TM-0362

only), and that further investigation would be necessary to prove the reliability of this method of operation. AGC memorandum No. 7760-M-3843 reports the results given above.

In-Cell Pace Boxes - Reference junction boxes similar to those used on the test car were mounted in Test Cell "A", and operated quite well. These units were still largely unsatisfactory for cryogenic measurements because of the large distances between the measurement point and the point of reference. Because of this distance, many transitions were made, and thermocouple effects could be observed on some of them. Estimates have placed errors on these measurements at about $\pm 12^{\circ}\text{R}$.

Effects of Wire and Junctions in Conductors on the Temperature Measurements - The large number of wire junctions existing between the point of measurement and the input to the data system at either Test Cell "A" or Test Cell "C" has resulted in considerable error in temperature measurements. Many writers (Messrs. W. Sibbit, C. Tallman, D. Liebenberg, R. Samuelson, and others) have shown the effect of wiring junctions to be as high as 14°R on a three sigma basis. All of these writers recommend the use of homogenous wire throughout the data system, a recommendation that cannot be put into practice because of the nature of the data systems themselves. Without exception these writers have shown that increased accuracies result when the thermocouple reference is moved as close as possible to the point of actual measurement, and when the system uses homogenous wire throughout.

Data System Errors - Large data system errors at Test Cell "A" have been encountered as reported in WANL-TME-1372. Transducer error, reference junction shift and other effects are small in comparison to the data system error. Nevertheless, these errors cannot be ignored, since their elimination would result in the improvement of the overall results. It seems likely that improvements in the data system cannot be made in time to show an increased accuracy for the NRX-A6 test. Indeed, attempts to evaluate the accuracies at Test Cell "C" have not yet been fruitful, and no definitive tests have been conducted. It has been agreed that data taken from EP-10A of Phoebus 1B test will be used for evaluation of data system accuracy, and if it is found that the results of Test Cell "A" are applicable to Test Cell "C", all parties will agree to use the same values in reporting the test cell accuracy. At this time no data have been received at WANL for analysis. See EI-7498 (ISFS-2214) for present scheduling.

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Thus, improvements in the referencing of thermocouples will be made on NRX-A6 in order to minimize this type of error on the cryogenic measurements.

3.0 SPECIAL PROBLEMS ASSOCIATED WITH THE NRX-A6 TEST

In some respects the NRX-A6 test presents a special and unique problem at Test Cell "C". Three means of referencing of thermocouples were available at the time choices were made in favor of the cryogenic reference located on the test car. These choices were 1) use of wells, 2) use of an in-cell Pace referencing system, and 3) on-the-car referencing using either a Pace reference junction box or a liquid nitrogen dewar. Whereas the wells at Test Cell "C" were in far better shape than those at Test Cell "A", the same general conditions exist as far as referencing: the exact well temperature is not always known, and there is an ever present possibility that moisture can enter the measurement from the well. It was therefore decided that wells would not be used for cryogenic measurements.

An insufficiency of copper-constantan cables passing through the car coupler prevented the use of the in-cell Pace references for all measurements. In addition, no constantan pins traverse the coupler. This is not a source of inaccuracy if the temperature is kept constant across the plug, but would be if the temperature varied.

Considerable work had been done by LASL and reported by Mr. C. Tallman in memorandum N-4°2447 concerning referencing of thermocouples close to the source of the measurement itself. It was concluded in this report: "The privy reference dewar appears to be the best solution to the copper-constantan thermocouple accuracy problem; therefore, we should like to adopt this approach prior to the Phoebe 1 test if there are no objections." Further work by Mr. R. Samuelson of AGC later verified the conclusions reached by Mr. Tallman and amplified them in REON technical memorandum RN-TM-0362, in which lead-wire-induced measurement uncertainties for copper-constantan channels were evaluated. In essence, the conclusion of this report was: the shorter the constantan lead in a copper-constantan thermocouple, the more likely were the results to indicate a favorable low-error measurement. Thus, in-cell referencing was considered to be a poor choice for the critical

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cryogenic measurements to be made on NRX-A6. It became obvious that an on-car referencing system was highly desirable, and the choice narrowed down to the use of Pace junctions or liquid nitrogen as a referencing medium for an in-car system.

4.0 SELECTION OF THE LN₂ DEWAR

The thermocouple curve shown in Figure 127 illustrates that for a 1 degree error in ice-bath referencing temperature, a 21.499 microvolt error may be seen at the input to the data system. When this error is reflected to a measurement at 70°R it may be seen that a 3.84 degree temperature error can be observed. If, however, the reference is at liquid nitrogen temperature the error observed becomes considerably less. It will be noted that a 1 degree error in the referencing temperature reflects itself as a 1.63 degree error in the actual measurement. Thus, assuming equal temperature shifts in the referencing temperature, the liquid nitrogen reference is somewhat better than the ice-point reference for cryogenic measurements.

Difficulties with the Pace reference junction boxes, as previously described, biased thought away from their use for NRX-A6.

At the time of final selection, LASL had been utilizing LN₂ referencing and had designed a dewar which was useable in the privy. The system was extremely simple, but required the use of a remote fill line for liquid nitrogen, which had been added to the cell-car interface. This line was available for use on the NRX-A6 car.

Also considered in the selection of the LN₂ dewar was the stability as a function of pressure shifts within the dewar itself. From Figure 128 it may be seen that a one psi pressure shift would influence the actual reference temperature by approximately 1.15°R. It was decided that attempts would be made to hold the pressure shift in the WANL dewar to less than one psi.

All of the factors covered above led to the selection of the in-car LN₂ dewar as the prime referencing means for WANL cryogenic measurements for NRX-A6.

It should be noted that the existing LASL dewar was not available for use on NRX-A6, because of the tight scheduling between NRX-A6 and the Phoebus 1B test at the time the original schedule was in effect. Thus, it was necessary for Westinghouse to 1) duplicate

Figure 127. Temperature - Millivolt Calibration Curve for Copper-Constantan Thermocouples
 (Reference Junction at 32°F)

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Figure 128. Vapor Pressure of Nitrogen

LASL's dewar for NRX-A6, or 2) to design a new dewar for NRX-A6. The latter course of action was chosen because, as may be seen from Figure 128, with the LASL valving as specified at the time of initiation of the WANL design, a 9.5 degree shift in temperature was possible assuming primary valve failure in the LASL dewar. It was decided that the Westinghouse dewar must maintain less than a 1.15 degree shift even with primary valve failure. If the primary valve does not fail, the temperature should remain constant to $\pm 0.5^{\circ}\text{R}$. If the primary valve of the LASL dewar does not fail, the temperature will remain constant to $\pm 4.9^{\circ}\text{R}$.

5.0 FEATURES OF THE NRX-A6 DEWAR DESIGN

The NRX-A6 dewar encompasses the following features:

- 1) A dual valving technique is utilized to prevent air from entering the dewar system, with the possible safety hazard as reported by Messrs. Tallman and Liebenberg in LASL memorandum CMF-9-1934E. The primary valve is set for 1/3 psi, with secondary valve backup at 1 psi. Thus, an extremely tight pressure tolerance is maintained on the valving system, yet one that is adequate to ensure that no explosion hazard exists.
- 2) Four resistors are mounted for level control with the dewar. They are mounted at 10, 25, 75, and 90 percent full.
- 3) The design is flexible, in that both sides of the copper-constantan thermocouples (copper and constantan) are referenced if desired, but terminal boxes are provided so that this is not necessary if not desirable. Some increase in accuracy can be obtained by referencing of both sides of the thermocouple, but the increase in terminations may offset this advantage.
- 4) The dewar has a capacity of 100 channels of copper-constantan referencing.
- 5) An automatic control system for remote filling of the dewar on an automatic basis has been designed. This feature will not be included in the NRX-A6 dewar, but is easily adaptable to the dewar at any time in the future. This feature has been provided to make the dewar an entity insofar as possible.
- 6) The dewar capacity is 40 liters. The boiloff rate due to all causes is 0.168 liters per hour. Included in the calculation for boiloff was the effect of gamma, convective, and

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conductive heating of the liquid (0.122 lit/hr) and heating by lead conduction (0.046 lit/hr). The liquid heating calculation is conservative, because it is based on an open-topped dewar, while the design actually employed is totally vacuum-jacketed.

6.0 CONCLUSIONS

After considerable study, an LN_2 dewar was selected for in-privy mounting to reference the cryogenic measurements for NRX-A6. The dewar previously designed by LASL was not available for use on this test because of schedular conflicts. A new dewar design, maintaining a close temperature referencing means has been provided and will be shipped prior to April 30, 1967.

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VIII. REFERENCES

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6. LASL Drawing No. 55Y-88092 - Reactor Cart Thermocouple Reference Dewar.

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