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CONTROL ACTUATOR

COMPONENT IRRADIATION TEST 14/W003

MASTER

Astronuclear Laboratory
Westinghouse Electric Corporation

NOV 20 1964

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	i
I SCOPE	1
II OBJECTIVE	1
III TESTED COMPONENTS	2
IV TEST INSTALLATION AND ENVIRONMENT	2
V TEST RESULTS	5
a. Potentiometer	11
b. Piston Seals	14
c. Torquemotor	18
d. Heat Transfer Measurements	27
VI TEST CONCLUSIONS	39
APPENDIX A: TEST SPECIFICATION 14/W003	
APPENDIX B: OPERATING PROCEDURE 14/W003	

ABSTRACT

The torquemotor, potentiometer, and piston-seals used in the first Generation Control Actuator were tested operationally to 10^{16} nvt at approximately 560°R. Operating performance results indicate the following:

- (a) Potentiometer -- no change in the mechanical or electrical properties as measured by the voltage smoothness and noise characteristics.
- (b) Torquemotor -- no change in the dynamic properties due to radiation. There seemed to be a minor change in the static gain characteristic, but not due to radiation.
- (c) Piston-Seal -- retained its strength properties, but evidenced a large increase (260 per cent) in friction values as the nvt built up. The apparent post radiation annealing does not reduce this problem.

In addition, the first attempt at a heat transfer evaluation of these components has indicated the following:

- (a) Potentiometer -- the potentiometer case is an extremely good conduction path for the heat generated internally and in the potentiometer housing cover.
- (b) Torquemotor -- the internal temperature (disregarding a minute hot-spot) should not exceed the incoming gas temperature by more than 50 - 60 degrees.

- (c) Piston-seal-cylinder -- indications are that the coolant passages around the cylinder sleeve are not as effective as expected, but they are sufficient to prevent an excessive temperature build-up.

I. SCOPE

Three of the first generation actuator components (torquemotor, potentiometer, piston-seals) had been dynamically tested in WANL Irradiation Test 14/W001 and 14/W002. While these tests had shown the parts to be mechanically sound with reasonable performance characteristics during and after irradiation, they were not sufficiently precise to pin-point the departures from normal performance due solely to radiation. Since these components are extremely important to the functional operation of the Control Drum actuator, an additional test was planned which would examine the dynamic operation with more precision. While a cold or low temperature environment is a more severe test for the components, it also introduces more uncertainty in the results. Transducers, fixtures, and test methods must be temperature independent or calibrated, and this is difficult. For good results, all factors (except the component) must remain constant over the 100 hour run time, and this is more difficult at low temperatures. Because of these factors it was decided that an ambient or near ambient test would give more definite results. To insure the near ambient conditions throughout the run, coolant gas would be provided to limit the temperature build-up due to gamma heating, and thermocouples would be used to record selected temperatures. It then became apparent that if some degree of precision were used in the location and reading of the thermocouples and if the flow were measured then one could obtain information on the heat transfer characteristics of the component in a known gamma heating environment. Based on these factors, the following test was designed.

II. OBJECTIVE

1. Primary

The primary objective was to measure and record the static and dynamic performance values for the torquemotor, potentiometer, and piston-seals while subjected to a known radiation field at ambient or near ambient temperatures. The following tabulation shows the static and dynamic parameters of interest.

<u>Component</u>	<u>Static</u>	<u>Dynamic</u>
Torquemotor	Inches/MA	Frequency Response
Potentiometer	Voltage Smoothness	Voltage Rate Change
Piston Seals	Deadband or Breakaway Friction	Hysteresis

2. Secondary

The secondary objective was to examine the heat transfer characteristics of the component and its cover based on coolant flow rate and temperature with a known gamma heating.

III. TESTED COMPONENTS

<u>Components</u>	<u>Identification</u>
First Generation Torquemotor	Servotronics, Serial Number 23-2B-56 Number 3
First Generation Potentiometer	Markite Type Number 8367
First Generation Piston-Seals	DePont SP Material and Machined by Koppers Company

IV. TEST INSTALLATION AND ENVIRONMENT

Figure 1 shows the front portion of the test assembly as the reactor would see it. The piston seal test fixture is on the right, the potentiometer fixture is on the left,

PALLET CONFIGURATION
WANL 14/W003

FIGURE 1

EAST PALLET, GTR, 14/W003						
Test Item	Total Gamma ERG/GM (C)	Average Gamma Rate ERG/GM/HR	Average Heating Rate		Total Neutron E > 2.9 MEV N/CM ²	Total Neutron E < .48 MEV N/CM ²
			WATTS/GM	BTU/SEC-Ib		
Torquemotor	1.75 X (11) *	1.75 X (9)	.0486	.0210	2.45 X (16)	6.5 X (14)
Potentiometer	0.87 X (11)	0.87 X (9)	.0242	.0105	1.6 X (16)	7.5 X (14)
Piston Seals	1.09 X (11)	1.09 X (9)	.0303	.0131	1.4 X (16)	5.4 X (14)
* Read As 1.75 X 10"						

TABLE 1

and the torquemotor fixture is in the middle at the bottom. At the top center is a tubing manifold for the coolant gas and the piston seal drive gas. The thermocouple terminal strip is at the bottom center, and one of the flow orifice fixtures at the bottom right. Not shown is the back of the pallet where the regulating valves, flowmeters, potentiometer drive motor and inertial disk, and interconnection devices are located behind a water cooled lead shield. In the test position the pallet face shown is moved against the reactor water wall so that the components in the fixtures are approximately 4 inches away from the wall.

In this position the components were subjected to the environment shown in Table 1 while the temperature was maintained at 550° - 560° R. During the test run, coolant gas was constantly supplied except for the changeover from nitrogen to helium, and the coolant rate was changed only for the heat transfer portion of the test. The test specification is attached as Appendix A, and block diagrams of the test arrangement are shown in Figures 2 and 3.

The components were operated approximately every four hours, according to the test procedure attached as Appendix B. In this manner component performance could be compared to previous WANL data. Not included in the test procedure is the heat transfer portion (temperature-flow measurement) which was spaced between the component runs. The procedure for this portion was defined on the first run where the trade-off between a measurable temperature and a measurable flow rate was evaluated. This is discussed further under the test results related to that part of the evaluation. Figures 4, 5, and 6 show the test assemblies for each component excluding the thermocouples and flow meters.

V. TEST RESULTS

Because of the difficulty usually encountered in reproducing Visicorder records, the traces shown were copied manually by carbon paper transfer. With normal care the original detail can be preserved.

LEGEND
 — COOLANT GAS
 - - - DRIVE GAS
 . . . FLEX DRIVE CABLE

REV	DATE	DESCRIPTION	BY	CHKD
1	12-1-62	PIPING SCHEMATIC		
2	12-1-62	GTR COMPONENT		
3	12-1-62	TEST		

REV	DATE	DESCRIPTION	BY	CHKD
1	12-1-62	PIPING SCHEMATIC		
2	12-1-62	GTR COMPONENT		
3	12-1-62	TEST		

REV	DATE	DESCRIPTION	BY	CHKD
1	12-1-62	PIPING SCHEMATIC		
2	12-1-62	GTR COMPONENT		
3	12-1-62	TEST		

REV	DATE	DESCRIPTION	BY	CHKD
1	12-1-62	PIPING SCHEMATIC		
2	12-1-62	GTR COMPONENT		
3	12-1-62	TEST		

TEST PALLET PIPING SCHEMATIC

FIGURE 3

TORQUEMOTOR TEST ASSEMBLY

FIGURE 4

POTENTIOMETER TEST ASSEMBLY

FIGURE 5

PISTON-SEAL-CYLINDER ASSEMBLY

FIGURE 6

a. Potentiometer

The circuit for this test permitted the recording of both wiper voltage and wiper voltage change versus time. If the two traces are taken simultaneously, then one can evaluate both the voltage rate change and its position on the voltage output characteristic. The potentiometer input was held at 10.0 volts and the wiper was rotated at approximately 7.5 rpm or .125 cps. Since any change in this speed would show up on the voltage rate trace, a large flywheel with a light friction brake was used to rapidly smooth out the speed variations. Several cycles were usually sufficient to eliminate this as a variable. Figures 7 and 8 show the general character of the traces taken throughout the reactor run. The voltage rate trace or noise trace as it is sometimes called represents by its height the instantaneous value of the voltage variation in the region of the film surface it is traversing. This makes it a very sensitive tool, but rather difficult to correlate with other parameters. Since our problem is one of the change in performance over the test run it is sufficient to examine the character of the trace, i.e. size and location of the discontinuities and abrupt slopes. All other parameters being constant, the potentiometer will duplicate the trace consistently in the manner of a signature. Note that the trace length or travel time varies slightly from trace to trace. This is due to slight differences in setting the drive motor speed, but it does not affect the character of the traces. For our purposes here, a height change of 1 inch would correspond to roughly a voltage rate change of .05 volts/degree.

All traces in Figure 7 are pre-irradiation runs and are nearly identical. Figure 8 shows the traces taken during the irradiation run. These, too, are nearly identical except for run Number 30 where the oscillations of the flywheel on the potentiometer input shaft were not allowed to smooth out before recording the data. Even so, the same sequence of peaks occurs in the proper order. This can be seen by overlaying any portion of the trace from one run on the traces from another run. In general, the noise represented here covers the frequency range from 1 to 100 cps which is well within the response range of the actuator electrical system. It therefore represents a valid test of this component.

14/W003
POTENTIOMETER TEST
IML-2"/SEC

14/W003
POTENTIOMETER TEST
IN-POSITION - 2"/SEC

POTENTIOMETER CHARACTERISTIC PRE-IRRADIATION

FIGURE 7

POTENTIOMETER TEST
14/W003 2"/SEC
RUN #2

14/W003
POTENTIOMETER TEST
3MW - RUN #25

14/W003
POTENTIOMETER TEST
3MW - RUN #30

POTENTIOMETER CHARACTERISTIC DURING IRRADIATION

b. Piston Seals

The arrangement of this test permitted pressure to be applied to the piston which was opposed by a spring equivalent to the actuator spring ratioed to that point. The pressure was therefore at the level normally encountered during no load operation of the actuator. The test specification then required that the complete hysteresis curve be taken, i.e. slowly increase pressure and then decrease pressure going from the start position to the stop position and back again, and recording both pressure and travel. Then move the piston to the 25, 50, and 75 per cent travel points and at each point evaluate the deadband or level of breakaway friction by moving slowly in each direction until the piston force exceeds the friction force and the piston suddenly moves. When plotted on graphs similar to Figures 9 and 10, the two different methods should reasonably check each other. In general, the relationship between pressure applied to a trapped seal and the frictional force is a complicated function of seal configuration, material bulk modulus, frictional coefficient, surface finish, and numerous other parameters. One would expect that as pressure increases, the force (breakaway) would increase if the surface normal to the pressure stays constant. Since this seal is rigid in comparison to, say, an O-Ring under the same conditions, we should expect the seal area changes to be a small factor in the pressure-friction relationship. However, the same rigid condition will allow an increase in the leakage flow as pressure increases. This tends to lubricate the seal-cylinder interface which effectively reduces the friction coefficient. We find that the relation of friction force (deadband) change to pressure change, dF_p/dp , has a positive slope, but decreasing in value as pressure increases. This is shown in Figure 11 for samples taken from the irradiation data. Run Number 1 does not conform, but can be disclaimed as an erroneous reading. The other samples show the general characteristic, and serve to point up the degree of radiation effect. In the seal (and its load the cylinder wall) is viewed as a black box, then the curves of Figure 11 represent the input-output function. Not only is the friction level increasing, but so is the slope. Returning to the mechanical aspect, the pressure is able to produce a greater effect on the seal as the total nv builds up, thus implying a weakening of the seal material or a

PISTON SEAL CHARACTERISTIC

FIGURE 9

PISTON-SEAL CHARACTERISTIC
FIGURE 10

PISTON-SEAL CHARACTERISTIC

FIGURE 11

change in the surface in contact with the cylinder wall. Based on the pre-irradiation values, the friction increase by Run Number 30 was approximately 260 per cent. This is higher than expected, but the remarkable part of the test was the recovery of the seal material when the post radiation examination was made. The friction level approximately two months after the radiation test fell to 117 per cent of the pre-irradiation values. This of course, opens to question the validity of the measurements, the possibility of change in the transducers, and numerous other points of cross-examination. The types of transducers used have been tested repeatedly by groups at WANL and found to have no more than a few per cent change due to radiation effects. A review of all the original data has exposed no factor which refutes the change during irradiation. Since the temperature was held reasonably constant by cooling the cylinder wall throughout the test, differential expansion of the seal-piston-cylinder would be unlikely. We must therefore conclude that the data is accurate. The reason for the change during irradiation we believe, is the usual degradation of material properties due to neutron bombardment and energy absorption. The reason for the high recovery remains undefined, and may be associated with the surface contacting the cylinder wall. For actuator purposes the high recovery after irradiation is not important since we are seeking to evaluate the problems during irradiation. The change of 260 per cent remains a substantial increase and must be considered in the evaluation of actuator loop stability and available output torque.

c. Torquemotor

The torquemotor examined in this test was the type normally encountered in small servovalves. Motion of the armature in this case is parallel to the flux path and the total available travel is in the order of .015" at a radius of .75" from the center of rotation. As defined in the specifications during each run a static and dynamic test was made. In the static test, current and travel (movement) were measured from one stop to the other stop and back again. The only restoring force opposing the current produced force was the internal gradient of the torquemotor. The internal gradient is itself a function of the mechanical spring (support the armature) and the spring effect

produced by the magnetic field in the air gap surrounding the armature at the pole pieces.

For the static case consider the following:

$$T = \gamma i$$

γ = current to torque constant of the torquemotor.

i = current.

T = torque.

$$K_g = K_s - K_m$$

K_s = internal spring rate of the armature.

K_m = magnetic spring rate of the armature between the poles.

K_g = net gradient of the torquemotor (total internal) without any external springs.

t = travel of the armature between the poles.

$$\Delta t = T / K_g$$

$$\Delta t = \Delta i \gamma / K_s - K_m$$

where

$$K_s > K_m$$

the two values measured were i and t

therefore:

$$\Delta t / \Delta i = \gamma / K_s - K_m$$

now, γ and K_m are both a function of the magnetic circuit and in general a weakening of the permanent magnet will reduce the value of both numbers. Rearranging we see,

$$\Delta t / \Delta i = \gamma / K_m / K_s / K_m - 1$$

thus a reduction in the properties of the permanent magnet will tend to decrease the ratio of t/i . This means less output motion (travel) for a given input current. The test was designed to observe this relation.

Figures 11 and 12 show the general character of the curves. Notice that the curve has a hysteresis value (shown by the distance between the two curves), an average slope (dt/di), and a current level to start motion. Figure 13 provides a comparison of the top portion of each of the sample curves. Several conclusions can be immediately drawn. As the test progressed, the current value to start motion increased, the left half of the characteristic retained about the same slope, and the right half showed a steadily increasing slope. By the time the post radiation examination was made the starting current was higher, the right half slope steeper, and the travel range increased. Due to instrumentation problems not related to radiation, the post radiation instrumentation was not the same as that used during the radiation runs. As a result, the exact level of the current is not certain and the travel measurement may be off by .0003 to .0004 inches. Nevertheless, the slope is correct and this is the important feature. Summarizing the curves in terms of numbers we can say that the pre-irradiation slope of .0038 in/ma decreased to .0029 in/ma by run number 30 and this change is in the order of 25 per cent. The post radiation examination showed an initial slope of .0036 in/ma (left half of curve), and a final slope of .0017 in/ma (right half). Figure 13 is a comparison of the upper portion of each of the test curves.

Since resolving the data requires some degree of familiarity with the torquemotor construction, let's postulate several solutions and see which best fits the data. If the permanent magnets had been weakened during the irradiation the entire slope would have increased (decreased dt/di). It is further inconceivable that only one or two poles of the torquemotor would have been weakened by radiation since the size of the torquemotor is small compared to the irradiation field. Suppose, however, that one of the pole pieces moved slightly (.001" to .002"). The symmetry of the magnetic circuit is altered and one region of travel could be affected without substantially altering the other region of movement. This would support the data taken over the full travel range. This same weakening would require a higher value of current to pull the armature away from the opposite pole pieces. This too supports the data.

If this line of reasoning is correct the frequency response (taken over the midrange of travel with an amplitude of perhaps .002") should show little if any effect. If the frequency response is good throughout the irradiation run then the controlling parameters have been unaffected to the integrated and dose rate conditions of the test.

The examination of the Figures 14 and 15 show little, if any, effect. Neglecting the first order lag of the transducer the amplitude characteristic changes only a few db and the natural frequency holds constant at $400 \text{ cps} \pm 20 \text{ cps}$. Run number 6 shows a phase lag change, but this is probably an error in measurement since later runs do not support the change. The natural frequency of the torquemotor as an unloaded component can be described as follows (using the previous nomenclature):

$$f_n = \frac{1}{2\pi} \sqrt{K_s - K_m} / J$$

where

J = moment of inertial about the armature support

f_n = natural frequency of the system.

The implication is that a change in any of these parameters would show up in the natural frequency. This is only partially true. A change in K_m at this frequency might not be evident at all. On the other hand the variations at low frequencies (where K_m changes would be pronounced) are not great. However, some effects can be seen in both amplitude ratio and phase lag. Examining all possibilities one must conclude that any change due to radiation must be small (order of a few per cent when operated in the actuator loop) with some portion of that per cent figure chargeable to movement of one of the magnetic poles during the test. Further ramification of this possible problem will be explored during non-irradiation vibration testing.

TORQUEMOTOR STATIC CHARACTERISTIC
FIGURE 11

TORQUEMOTOR STATIC CHARACTERISTIC

FIGURE 12

TORQUEMOTOR CURVE COMPARISON

FREQUENCY RESPONSE CHARACTERISTIC

FIGURE 14

FREQUENCY RESPONSE CHARACTERISTIC

FIGURE 15

d. Heat Transfer Measurements

To properly evaluate the heat transfer conditions for each of the tested components one would need a considerable number of measurements with several trials to confirm the results. In a test of this sort this is not possible. Since a high coolant flow rate (easy to measure) also means a low temperature differential, care must be exercised in the trade off in order to obtain good readings of each. As a result, the test conditions were a compromise and the conclusion drawn should be considered only approximately correct. In order to evaluate the case of hydrogen flow in the actuator versus the test conditions one would require similarity in three areas, geometric, kinematic, and dynamic. The geometric similarity was approximated to a fair degree by the component covers, and method of component mounting. Since the test required steady state temperatures rather than transient we assume that kinematic effects are negligible. The dynamic portion is considered the least correct in all tests. In order to alleviate part of the problem the tests were made with two different gases. Consider the following properties:

<u>Property</u>	<u>G A S</u>		
	<u>He</u>	<u>N₂</u>	<u>H₂</u>
Thermal Conductivity, K (BTU/HR-FT-R)	0.0818	.0131	0.0966
Specific Heat (BTU/LB-R)	1.25	.247	3.42
Density ₃ (LB/FT ³)	0.0112	.078	0.0052

In all respects helium more closely approximates the hydrogen characteristics. Nitrogen is rather far removed, however, the use of nitrogen would tell us the range of possible variations. Thus a test with the closest approach to hydrogen and one that is quite far removed would provide some insight to the heat transfer conditions. The component tested is discussed individually in order to analyze the results of each.

Tables 2 and 3 show the reduced data from the tests. Note in Table 2 that the component heat generation rate is small in each case compared to its cover or housing. This duplicates the true actuator situation.

Torquemotor

The schematic of the test arrangement is shown in Figure 15. Because of the flow symmetry we can assume that all the heat generated in the torquemotor is picked up by the gas, and further that the use of an average gas temperature, $T_g = T_i + T_o/2$ is valid. We can then compute the following values:

<u>Test Gas</u>	<u>Test Flow</u> SCFM	<u>Temperature</u>		<u>Computed</u> <u>$\bar{h}A$</u>
		<u>T_g</u> DEG	<u>$T_g - T_e$</u> DEG	
N ₂	1.92	105.2	15.8	1.82 BTU/HR-°R
N ₂	2.71	101.0	22.5	1.28
He	5.10	110.2	17.8	1.62
He	7.20	104.5	12.0	2.40

This gives an average surface conductance of 1.55 for N₂ and 2.01 for He. If we can assume 10 in² of surface area we have,

$$\bar{h} = 22.3 \text{ Btu/hr} - \text{ft}^2 - \text{R for nitrogen}$$

and
$$\bar{h} = 29.0 \text{ Btu/hr} - \text{ft}^2 - \text{R for helium.}$$

Another point worth noting was the temperature distribution. The component which was quite isolated from any conduction path tended to be about 27° hotter than the incoming gas temperature independent of the type of gas. Since the actuator heat generation rate

TABLE 2
HEAT GENERATION

Potentiometer

<u>Item</u>	<u>Average Value Heat Rate</u>	<u>Weight</u>	<u>Heat Rate</u> BTU/SEC
Cover	.0105 BTU/lbs. - second	1.78 lb.	.0187
Component	.0105 BTU/lbs. - second	.06 lb.	.0006

Torquemotor

<u>Item</u>	<u>Average Value Heat Rate</u>	<u>Weight</u>	<u>Heat Rate</u> BTU/SEC
Cover	.0210 BTU/lbs. - second	1.85 lb.	.0388
Component	.0210 BTU/lbs. - second	.38 lb.	.0080

Piston-Seal

<u>Item</u>	<u>Average Value Heat Rate</u>	<u>Weight</u>	<u>Heat Rate</u> BTU/SEC
Housing	.0131 BTU/lbs. - second	9.3 lb.	.1220
Cylinder and Seals	.0131 BTU/lbs. - second	.34 lb.	.0445

TABLE 3
STEADY STATE CONDITIONS

Potentiometer

<u>Gas</u>	<u>SCFM Flow</u>	<u>Ti</u> DEG	<u>To</u> DEG	<u>Tc</u> DEG	<u>Tw</u> DEG	<u>Ti-To</u> DEG	<u>Heat Rate</u> <u>Absorbed</u> BTU/SEC
N ₂	1.74	93	112.	100.	107.5	19.	.0100
N ₂	2.51	88	106.5	94.5	103.	18.5	.0140
He	4.62	97	110.	104.	106.	13.	.0129
He	6.66	92	108.	99.	101.	16.	.0230

Torquemotor

<u>Gas</u>	<u>SCFM Flow</u>	<u>Ti</u>	<u>To</u>	<u>Tc</u>	<u>Ti-To</u>	<u>Heat Rate</u> <u>Absorbed</u>
N ₂	1.92	97.5	113	121.	15.5	.0090
N ₂	2.71	93.0	109	123.5	16.	.0131
He	5.10	98.5	122	128.	23.5	.0258
He	7.20	93.0	116	116.5	23.0	.0356

Piston-Seals

<u>Gas</u>	<u>SCFM Flow</u>	<u>Ti</u>	<u>To</u>	<u>Tw</u>	<u>Ti-To</u>	<u>Heat Rate</u> <u>Absorbed</u> BTU/SEC	
N ₂	2.56	91	126.5	.	122.5	35.5	.0274
N ₂	3.68	89	121.		111.	32.	.0355
He	6.80	90	116.		111.	26.	.0380
He	9.78	88	113.		110.	25.	.0525

SCHEMATIC
TORQUEMOTOR INSTALLATION

FIGURE 16

SCHEMATIC
POTENTIOMETER INSTALLATION

FIGURE 17

is approximately twice the GTR value the implication is that the torquemotor temperature would be 50-60° higher for hydrogen (than 29 for helium) will help to insure the 50° temperature excess even though the mass flow rate for hydrogen is somewhat lower than the tested conditions.

Potentiometer

Figure 16 shows the schematic of the potentiometer installation. Note that the portion of the flow allowed to leak past the mounting wall is small compared to the portion moving through the pot shaft region. Reference to Table 3 again shows the temperature distribution. Due to technical problems it is not possible to measure the temperature down inside the pot itself without interfering with the operation. However, it is possible to estimate the temperature based on inlet, outlet, and cover wall temperatures. When this is calculated for each test run one is forced to conclude that the gas in the shaft region is always hotter by 1° or 2° than the potentiometer case. We know further that the gas temperature external to the pot is also hotter than the pot case in the order of 3 or 4°. We are forced to conclude that the potentiometer case is an extremely good conduction path which holds true for both helium and nitrogen under both flow rates. This was unexpected, and causes some problem in the reduction of the data. We know that there is some convection over the outside of the test cover, but not the amount. As a result the amount of heat picked up by the gas before entering the pot shaft region is not known. If it were known, that number less the heat associated with the outlet temperature would be the part conducted away by the potentiometer case. From this, an $\bar{h}$ could be computed, but with many assumptions. Assuming that the first helium run is valid then the heat conducted through the pot case is .0187 - .0129 = .0058 Btu/sec. For that run the temperature difference from gas to case is about 1 to 2°. Then

$$\bar{h} A = .0058 \times 3600/2 = 10.4 \text{ Btu/hr -R}$$

and assuming the inner surface of the case is the major heat transfer area (equal to 4.7 in²)

$$\bar{h} = 10.4 \times 144/4.7 = 319 \text{ Btu/hr} - \text{ft}^2 - \text{R.}$$

This is about 30 per cent higher than previous estimates, but seems to be valid.

The potentiometer case was, in general, 3 or 4° hotter than the incoming gas, and the plastic parts could be no more than 13 to 20 degrees higher than the incoming gas. Doubling the heat generation, rates should not more than double the temperature excess and if so no internal part would exceed 40° over the incoming gas. This in itself seems to be no problem.

Piston Seal-Cylinder

Figure 17 shows the schematic diagram for this test installation. It would have been desirable to know the temperature of the seals during the test runs, but this was not possible without interfering with the operating performance. The attempt here is to consider the cylinder, piston, and seals as a unit heat load. Using $T_g = T_i + T_o/2$ the following values can be computed for the wall:

<u>Gas</u>	<u>Flow</u>	<u>T_g</u>	<u>T_w - T_g</u>
N ₂	2.56	109	13.5
N ₂	3.68	105	6.0
He	6.80	103	8.0
He	9.78	101	9.0

This gives an average difference of 9.1° from the wall to the gas and if 75 per cent of the housing heat load can be picked up by the gas then,

$$\bar{h} A = .1220 \times .75 \times 3600/9.1 = 36.2 \text{ Btu/hr} - \text{R.}$$

SCHEMATIC
PISTON-SEAL-CYLINDER INSTALLATION

FIGURE 18

TEST POTENTIOMETER
WANL 14/W003

FIGURE 19

DISASSEMBLED TORQUEMOTOR
WANL 14/W003

FIGURE 20

PISTON-SEAL-CYLINDER
WANL 14/W003

FIGURE 21

Since the surface area inside is about 30 in² an average value of

$$\bar{h} = 3.62 \times 144/30 = 17.5 \text{ Btu/hr} - \text{ft}^2 - \text{R}.$$

This is a low value, and further, the wall to gas temperature difference was expected to be around 2 to 3°. It would seem that the cooling passages are not as effective as expected. Without the cylinder temperatures, it is impossible to estimate the average $\bar{h}$ value for the piston-seal-cylinder volume. It can be said that the average wall temperature is some 30° over the inlet gas temperature, and with drive gas continuously leaking and cooling the piston the inside should not exceed that value. This being true the seals have no temperature problems, however, further tests are required to prove this.

VI. TEST CONCLUSIONS

Figures 18, 19, and 20 show the general mechanical condition of the components after the irradiation runs. Note that a potentiometer terminal was lost during the disassembly process and has no bearing on the mechanical integrity of the test item.

The results of the testing indicate that the potentiometer showed no degradation in the operating performance when examined over the frequency range of interest to the actuator. Any change in the mechanical integrity of the parts would have been evident in the measured traces. Further, the condition of the track (resistive element) was apparently unchanged since the magnitude of the peaks and their location in the trace was unaffected. We must conclude the potentiometer is good to the irradiation level of the test. The heat transfer portion showed that the case is extremely good conduction path and the potentiometer should be no higher than 10° above the incoming gas temperature.

The torquemotor performance was good except for the apparent movement of one of the pole pieces. This is seen to be a problem to be examined further under vibration, but for the dynamic operation it seemed of no consequence. The natural

frequency was not affected, and the static gain retained very nearly its original slope. The current level to produce initial movement changed slightly, but this amounts to a small d.c. bias which would not disturb the closed loop operation. The heat transfer measurements showed good values for the torquemotor and cover with acceptable temperatures in each case relative to the incoming gas temperature.

The piston seal test indicated good values as expected at the beginning of the test. The seals tested slowly degraded to the high value of 10 psi. In terms of torque at the actuator shaft this represents a loss of 22 in - lbs. per seal. The seal however, showed a high level of recovery after radiation. The conclusion which has no direct proof is a change in surface condition during radiation which was wiped away or eliminated during the post radiation tests. In addition, the heat transfer portion of the test showed that high wall (external) temperatures occurred which was supported by an unusually low surface conductance for the cooling passages. The inner cylinder wall temperature could not be measured and we have no direct check of the temperature of the seals. Whether this has a bearing on the seal friction problem is for the present unknown.

As far as the actuator is concerned the piston seals remain an area needing further investigation when subjected to radiation. An additional test concentrated solely on the piston-seal-cylinder parameters would resolve the issue.

APPENDIX A
TEST SPECIFICATION
14/W003

TEST SPECIFICATIONS

I. Experiment Identifications

A. Test Plan Reference Number	14/W003
B. Sponsors	WANL, Control Development
C. Testing Agency	GTR
D. Test Date	February 29, 1964

II. Purpose of the Experiment

The primary goal is to operate the actuator components at near ambient conditions in a nuclear environment. As a secondary goal, the level of operating performance will be examined along with the combined effects of gamma heating and power dissipation. Efforts will be made to determine if localized heating occurs within the components.

The following components will be evaluated:

- A. Torque Motor. Permanent magnet type with rotating armature. The same type previously tested at 140°R.
- B. Potentiometer. Film type previously tested at 140°R.
- C. Piston Seals. DuPont SP type previously tested at 140°R.

III. Drawings

A. Test Items

1. Potentiometer Test

a. Details	386D681
b. Details	386D682
c. Assembly.	386D683

2. Torque Motor Test

a. Details	576F038
b. Assembly	386D686

3. Piston Seal Test

- a. Details 574F125
- b. Details 574F133
- c. Details 386D687
- d. Assembly 710J113

" Electrical Single Line - 386D690

C. Hydraulic Single Line - Not Applicable

D. Pneumatic Single Line - 386D689

IV. Equipment List

A. To be provided by NERVA:

- 1. Components (Section II), mounting brackets, and mounting plates.
Complete for mounting on pallet.
- 2. Potentiometer drive motor, flexible shaft, and mounting.
- 3. Pressure regulator and control for piston seal test.
- 4. Amplifiers and switching to match readout.
- 5. Visicorder 906C and galvanometers.
- 6. Pressure transducers.
- 7. Thermocouples and thermocouple balance, reference, and control
units for galvanometer readout.

B. To be provided by tester:

- 1. Cables, pallet to control room.
- 2. Nitrogen supply at 300 psig.
- 3. Shielding for drive motor and regulators.

V. Test Environment

- A. Temperature ~ 540°R, 800°R Max.
- B. Pressure: Internal to components 250 psig Max.

C. Humidity	Not Applicable
D. Vibration	Not Applicable
E. Fast Neutron Flux, $>.1$ MEV	3.1×10^{11} N/CM ² /Sec.
F. Thermal Neutron Flux	6×10^9 N/CM ² /Sec.
G. Gamma Flux	2.2×10^5 ERG/GM/Sec.
H. Integrated Flux	
1. Fast Neutron, $>.1$ MEV	5.58×10^{16} N/CM ²
2. Thermal Neutron	1.1×10^{15} N/CM ²
3. Gamma	4×10^{10} ERG/GM
I. Fluid Environment	Not Applicable
J. Duration	100 hours or earlier if a component fails

VI. Analytical

A. Predicted Perturbed Flux	83% of Unperturbed Flux
B. Radiation Heating	Sufficient gas flow for cooling is provided to maintain temperatures below about 700°R
C. Activation Levels	

Levels may be calculated from the materials list as follows:

Aluminum	27 lbs.
Stainless Steel	5
Brass	1
Hypernik	$\frac{1}{4}$
Alnico No. 5	$\frac{1}{4}$
Inconel X	$\frac{1}{4}$

VII. Facility Requirements

It will be necessary to examine and photograph all components as soon as possible after the test is completed.

VIII. Dosimetry

Fast neutron and gamma dosimeters at front and rear of cryostat is necessary.

IX. Data Handling Requirements

Provide copies of visicorder traces.

X. Test Procedure

Attached.

XI. Hazards

None.

XII. Data Reduction Required

None.

XIII. Disposition of Hardware

A. Hold test items and fixtures for disposition instructions at completion of post-irradiation testing.

B. Return amplifiers and control equipment to WANL at completion of test.

XIV. Shipping and Receiving Instructions

A. All WANL items will be shipped to Mr. B. L. Lanford at GD/FW.

B. Items to be returned to WANL should be marked for Actuator Laboratory, Control Development, Building #5, Attention: Paul R. Greenaway.

XV. Appendix

None.

APPENDIX B

TEST PROCEDURE

14/W003

TEST PROCEDURE

I. GENERAL

- A. Primary Goal: The primary goal is to operate the actuator components at near ambient temperatures in a nuclear environment. The potentiometer will be rotated at a constant velocity, while operating as a voltage divider. The voltage output and the derivative of the voltage output will be observed for any change in characteristics. The torque motor will be cycled with no load. The frequency response, phase shift, and static gain will be observed. Two piston seals will be operated on a piston in a special cylinder. The dead band will be observed at 25%, 50%, and 75% of travel as a measure of friction.
- B. Secondary Goal: As a secondary goal, the components will be screened for hot spots. Cooling gas is provided to attempt to moderate the temperatures.
- C. Operation:
1. Potentiometer
 - a. Measurands
 1. Primary Goal
 - a. Voltage
 - b. Voltage Derivative
 - c. Event Marker (Rotation)
 2. Secondary Goal
 - a. Coolant Pressure
 - b. Coolant Inlet Temperature
 - c. Coolant Exhaust Temperature
 - d. Potentiometer Body Temperature
 - e. Temperature of Outside of Chamber

- b. Description of Operation: The potentiometer is rotated by an electric motor through a speed reducer and a flexible cable. A flywheel and brake are mounted on the shaft to damp out speed variations in the gears and flexible shaft. The potentiometer is operated as a voltage divider. The voltage output is taken from the wiper to the common side. However, a trace of voltage is not precise enough to observe changes in performance at the level desired. Therefore, the output is also put through a derivative circuit to show the rate of change in the voltage. This output is then amplified to show the very low level of performance that must be observed. A cam operated microswitch was included on the shaft. In case of failure, the microswitch will show whether or not it was due to the drive mechanism or the potentiometer and its circuits.

2. Torque Motor

a. Measurands

1. Primary Goal

- a. Torque Motor Current
- b. Torque Motor Voltage
- c. Armature Travel

2. Secondary Goal

- a. Coolant Pressure
- b. Coolant Inlet Temperature
- c. Coolant Exhaust Temperature
- d. Torque Motor Body Temperature

- b. Description of Operation: The torque motor will be operated with no load, in order to eliminate variables external to the motor.

The static characteristics will be observed by manually stepping the motor and recording the travel through its entire range. The dynamic characteristics will be measured while commanding the motor with a sine function from 0.5 cps to over 400 cps. Travel will be set for ± 0.001 inch about the median point.

3. Piston Seals

a. Measurands

1. Primary Goal

- a. Cylinder Drive Gas Pressure
- b. Piston Travel

2. Secondary Goal

- a. Coolant Pressure
- b. Coolant Inlet Temperature
- c. Coolant Exhaust Temperature
- d. Temperature of Outside of Cylinder
- e. Drive Gas Temperature

- b. Description of Operation: The piston seals are fitted on an actuator piston. The piston will operate in a cylinder by gas pressure against a coil spring. The dead band will be measured by slowly reversing direction of travel at several positions in midrange and recording pressure and travel.

D. Operating Instructions:

- 1. Turn on the pressure transducer power switch.
- 2. Turn on the nitrogen supply at the regulator to 200 psig.
- 3. Turn on the visicorder, but do not plug the cable into the rack.
- 4. Turn on the galvanometer amplifier.
- 5. Turn on thermocouple reference junction on the back of rack.

6. Turn on switch for potentiometer transducer.
7. Turn the function switch on the potentiometer test panel to pot test position.
8. Set potentiometer drive motor speed control to 15 on the dial, low range, and forward direction. Run the motor for at least 30 seconds before recording data.
9. Turn on the AC switch of the Philbrick 300 VDC Power Supply. Wait 20 seconds, then turn on the DC switch.
10. Set the visicorder paper speed at 2 inch/second.
11. Set the visicorder timing lines at 1 second interval.
12. Plug the visicorder cable into the potentiometer receptacle on the rack.
13. Turn the voltage adjust knob of the pot power supply counter-clockwise to its minimum setting.
14. Turn the pot power supply meter range switch to 10 volts.
15. Turn the pot power supply short circuit current switch to 25 ma.
16. Turn on the pot power supply.
17. Slowly raise the voltage to 10.0 volts.

NOTE: The sudden or rapid application of voltage will overdrive the galvanometer.

18. Turn on the event marker.
19. Record three cycles at 2 inches/second paper speed and three cycles at 10 inches/second paper speed.

NOTE: At the desired motor speed, the voltage and the noise trace will be 4 seconds long each, for 180° of rotation. At this speed, the deflection of the noise trace will average 2.7 inches. If the noise deflection should vary significantly from 2.7 inches, the drive motor control may be adjusted

slightly to compensate. This will probably have to be done if the pot noise level degrades during the test, just to keep the trace on the paper.

20. After the data has been recorded, shut off the event marker, the drive motor, and the potentiometer pressure transducer.
21. Turn on the torque motor pressure transducer.
22. Turn the function switch on the potentiometer test panel to torque motor test position.
23. Turn on the power switch on the lower left-hand side of the torque motor control panel.
24. Turn on the bias voltage on the torque motor control panel.
25. Plug the visicorder cable into the torque motor receptacle on the rack.
26. Operate the command voltage manually and check the visicorder trace for travel.
27. Slowly command the torque motor from one stop to the other stop and back again.
28. Command the torque motor up and back again in 0.5 ma steps, pausing several seconds at each step.
29. Hook up a Hewlett-Packard Function Generator to the signal input jacks of the torque motor control panel.
30. Set the frequency to 0.5 cps and the function to sine wave.
31. Turn the amplitude to zero.
32. Manually command the motor to exactly midpoint of travel.
33. Turn on the signal input switch.
34. Adjust the output control to ± 0.001 inch of travel about the midpoint.
35. Record several cycles at each of the following frequencies: 0.5 cps, 1.0, 5.0, 10.0, 20, 40, 65, 100, 150, 200, 250, 300, 350, 400, and 450.

Note the amplitude of the torque motor current trace and try to maintain a constant amplitude as far as is possible. Watch for resonance around 350 cps.

36. Shut off bias voltage, power switch, torque motor pressure transducer, the Philbrick 300 VDC Power Supply, and the function generator.
37. Turn on the cylinder pressure and cylinder coolant pressure transducer.
38. Turn on the LVDT transducer supply.
39. Plug the visicorder cable into the piston seal receptacle on the rack.
40. Turn in the cylinder pressure regulator and check for travel on the visicorder.
41. Slowly move the piston out to $1\frac{1}{2}$ inches travel.
42. Slowly lower the pressure to reverse the direction, and return to zero pressure.
43. Slowly raise the pressure to close to $\frac{3}{8}$ inch of piston travel.
44. Turn the cylinder travel control on the galvanometer amplifier to maximum.
45. Slowly raise the pressure to $\frac{3}{8}$ inch of piston travel.
46. Slowly reverse direction and return to zero.
47. Turn the cylinder travel control on the galvanometer amplifier back to the original setting.
48. Check the original setting by noting the zero point and the full travel point.
49. Repeat Steps 38 through 45, except stop at $\frac{3}{4}$ inch instead of $\frac{3}{8}$ inch.
50. Repeat Steps 38 through 45, except stop at $1\frac{1}{8}$ inch instead of $\frac{3}{8}$ inch.
51. Shut off the cylinder pressure transducer, cylinder coolant pressure transducer, and the LVDT transducer supply.