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IRRADIATION TEST OF SNAP 8 ACTUATORS,
POSITION SENSORS, AND LIMIT SWITCHES

AEC Research and Development Report

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IRRADIATION TEST OF SNAP 8 ACTUATORS,
POSITION SENSORS, AND LIMIT SWITCHES

By

N. F. DAVIES
W. J. KURZEKA
M. WARREN

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ABSTRACT

Two control-drum-drive actuators, two control-drum position sensors, and two shorting-bar limit switches were tested in a combined radiation, vacuum, and high-temperature environment. The components represented the current SNAP 8 design. The purpose of the test was to evaluate the effects of the combined environment on the components prior to their use in the SNAP 8 Developmental System (S8DS) test.

The test environment had no apparent effect on the performance of the components during any phase of the experiment. Data on coil resistances, electrical insulation resistances, and temperatures were measured in-pile throughout the experiment.

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I. INTRODUCTION

The purpose of this test was to expose SNAP 8 Developmental System (S8DS) reactor control components to a combined high-temperature, high-flux, and vacuum environment, simulating conditions to be imposed during testing of the S8DS system. The SNAP 8 Reactor System is being developed for the AEC by Atomics International.

In the experiment described, two S8DS control-drum-drive actuators, two position sensors, and two limit switches were irradiated to total doses from 1 to 8×10^{18} nvt ($E > 0.1$ Mev) and from 0.6 to 1.5×10^{10} r. The operating temperatures were 1000°F for the actuators, 800°F for the position sensors and 1000°F for the limit switches. System pressure ranged from 10^{-5} to 10^{-6} torr, decreasing as the experiment progressed. The test components were maintained at operating temperatures for 3000 hr, and received 2313 hr of radiation.

The experiment was performed at the Battelle Research Reactor (BRR) of the Battelle Memorial Institute, Columbus, Ohio. In-pile measurements were made of the conductor resistances and electrical insulation resistances of the test components. Contact resistances of the limit switches were also measured. The control drum drive actuators were operated at specified regular intervals during the radiation experiment. The operating stability of the limit switches and position sensors was measured during these functional tests.

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Figure 1. S8DS Actuator, Exploded View

II. TEST COMPONENT DESCRIPTION

A. CONTROL-DRUM-DRIVE ACTUATOR (SN 003 Upper and SN 004 Lower)

The S8DS actuators are electromagnetic stepping motors equipped with a brake. The actuators employ solid rotors with "wet-wound" stator and brake coils. Conductors are glass-covered chrome-plated copper insulated with SAP II, an AI-developed high-temperature encapsulant. All structural parts, including the rotor, are made of Hiperco 27. The brake surfaces have matching teeth, which are engaged to provide braking action. The mating surfaces of the teeth are coated with dry-film lubricant to inhibit self-welding. Bearings are made of carbon graphite and aluminum oxide. An exploded view of the actuator is shown in Figure 1. The actuator shaft rotates 1.8 deg arc per actuation.

B. DRUM POSITION SENSOR (SN 006 Uper and SN 008 Lower)

The drum position sensor is a rotary differential transformer containing a primary and two secondary coils. The primary coil is excited with alternating current (400 cps at 10 volts) producing an ac output which varies in amplitude in relation to the shaft angle. An exploded view of the sensor is shown in Figure 2. The coil conductors are chrome-plated copper insulated with SAP II. Other materials are shown in the figure. The position sensor is used in conjunction with a demodulator which converts the sensor output signal to a proportional dc output voltage.

C. LIMIT SWITCH

The limit switches shown in Figure 3 are used on the S8DS reactor to indicate control drum limits. Materials used in the construction of the switch are also shown in the figure.

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Figure 2. S8DS Position Sensor, Exploded View

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Figure 3. S8DS Limit Switch

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Figure 4. Radiation Test Assembly (HF-10)

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III. FACILITIES, TEST ASSEMBLY, AND ENVIRONMENT

A. IRRADIATION FACILITIES

The irradiation was performed at the BRR, which is a 2-Mw pool-type research reactor. The reactor normally operates on a 12-day irradiation cycle at full power, followed by a 2-day shutdown between cycles. The location of the fuel elements in the core was altered to create a pocket in the front face to accommodate the capsule and associated shielding.

An 8-in.-diameter, 56-in.-long aluminum capsule was used to house the test components. The pipe was flanged at the top and was connected by approximately 30 ft of 8-in.-diameter pipe to the vacuum system which was located above the surface of the pool. Ion vacuum gages were located at the top of the capsule in the upper pipe and at the ion vacuum pump.

B. TEST ASSEMBLY

The test assembly consisted of two independent assemblies. The upper assembly consisted of an actuator and a position sensor, while the lower assembly contained an actuator, a position sensor, and two limit switches. The overall test setup is shown in Figure 4.

One requirement of the experiment was to determine whether the actuators would produce a minimum of 20 oz-in. of dynamic torque during in-pile exposure. A system of weight suspended from a cable was provided to vary the rotational resistance load on the rotor from approximately zero at the zero-step position, to 20 oz-in. at the 28-step position. Figure 5 shows the lower assembly with torque-weight attached. The figure also shows the limit switches riding on the cams which actuated them. The position sensors and actuators were coupled together with a spring clip device that would disconnect the two in case of position sensor bearing failure.

An auxiliary position sensing device was also incorporated into each assembly. This device consisted of a magnetic pickup used in conjunction with teeth of various sizes machined on the torque pulley-wheel. As the teeth passed in front of the magnetic pickup, a change of magnetic flux induced a signal in the magnet coil, and, since the teeth were of different sizes and in a coded sequence,

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Figure 5. Lower Actuator - Torque Weight Assembly (HF-10)

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the rotational position of the actuator shaft could be determined. The output of this device was recorded on a Moseley autograph recorder. Additional details of the BRR irradiation facility and the torque and secondary positioning devices are contained in NAA-SR-10717.*

The main support structure was made of stainless steel while the heater support posts, baffles, and heaters were made of refractory metals to limit contamination due to material evaporation.

C. TEST ENVIRONMENT

1. Nuclear

The operational history of the BRR during the experiment is shown in Table 1, while total radiation exposures are shown in Table 2. Mockup dosimetry measurements were made throughout the capsule volume prior to the experiment to determine neutron spectra and distributions of neutron fluxes and gamma dose rates. The thermal neutron flux distribution was measured using both bare and cadmium-covered cobalt wire dosimeters. Resonance neutron distribution was also determined with similar cobalt wire dosimeters and an assumed spectral function. The fast spectra was determined using threshold detectors. The gamma dose rate distribution was measured with a graphite-walled ionization chamber.

The in-pile neutron exposures were measured using two types of wire dosimeters mounted at selected positions in the assembly. Iron wires were used for the fast dose determination while zirconium-cobalt wires were used for the thermal dose. Resonance neutron exposures were calculated from the fast exposures, applying ratios of resonance to fast fluxes as measured simultaneously in the mockup capsule. Gamma doses were determined from the mockup measurements, specimen location, and irradiation time.

2. Temperature

Temperature profiles were achieved by dividing the assembly into seven temperature zones. These temperature zones were separated by twin horizontal

*M. Warren, "Irradiation of SNAP 10A Control Drum Drive Actuators and Position Sensors," NAA-SR-10717 (May 15, 1965)

TABLE 1
SUMMARY OF BRR OPERATIONS DURING EXPERIMENT
(Sheet 1 of 2)

Date (1965)	Time (hr)	Accumulated Hours at 2 Mw	Remarks
August 4	1300		Reactor at 100 kw
	1320		Reactor at 400 kw
	1338		Reactor at 1 Mw, Cycle 189
August 5	1334	12	Reactor shutdown, out-of-pile
August 18	1433		Reactor at 1 Mw, Cycle 190
	1446		Reactor at 2 Mw
August 30	1025	295.8	Cycle 190 shutdown; out-of-pile
September 1	1456		Cycle 191 startup
September 2	1649		Reactor subcritical
	1728		Reactor at 2 Mw
September 13	1000	578.2	End Cycle 191
	1000		Start Cycle 192
September 14	1415		Reactor subcritical
	1455		Reactor at 2 Mw
September 15	0034		Reactor scram
	0225		Reactor at 2 Mw
September 27	1000	911.7	Cycle 192 shutdown; out-of-pile
September 30	1435		Cycle 193 startup*
October 5	0501		Reactor scram
	0800		Reactor at 2 Mw*
	1601		Reactor scram
	1745		Reactor at 2 Mw*
October 6	0800		Reactor scram
	1018		Reactor at 2 Mw*
	1040		Reactor scram
	1228		Reactor at 2 Mw*

TABLE 1
SUMMARY OF BRR OPERATIONS DURING EXPERIMENT
(Sheet 2 of 2)

Date (1965)	Time (hr)	Accumulated Hours at 2 Mw	Remarks
October 7	0825		Reactor scram
	1100		Reactor at 2 Mw*
October 12	0536		Reactor scram
	0742		Reactor at 2 Mw
October 13	1729	1218.1	End Cycle 193; electrical power failure
October 15	1555	1788.9	Cycle 194 startup*
November 8	1005		Reactor at 1 Mw
	1015		Cycle 194 shutdown; out-of-pile
November 11	1722		Cycle 195 startup*
	1740		Reactor scram
	1828		Reactor at 2 Mw*
November 29	1728	2312.8	Reactor scram
	2020		Reactor at 2 Mw*
November 30	0242		Reactor scram
	0446		Reactor at 2 Mw*
	0815		Reactor scram
	1150		Reactor at 2 Mw*
	2040		Reactor scram
December 3	1406		Reactor at 2 Mw*
December 6	1313		Reactor at 1 Mw
	1334		Cycle 195 shutdown; end of irradiation

*The reactor was operated at several partial power levels during these startups. The partial power operation is factored into the accumulated time.

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Figure 6. Radiation Test Assembly with Instrumentation,
Less Heaters (HF-10)

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TABLE 2
RADIATION EXPOSURES

Component	Neutron Dose* (10^{18} n/cm ²)			Gamma Dose (10^{10} r)
	Thermal	Resonance	Fast	
Upper Assembly				
Position Sensor	0.82	0.82	1.73	0.67
Actuator	0.31	1.86	4.18	1.12
Actuator Brake	0.51	3.22	7.05	1.26
Lower Assembly				
Position Sensor	1.05	3.79	6.68	1.03
Actuator	0.68	4.02	8.16	1.50
Actuator Brake	0.56	3.79	8.06	1.37
Limit Switches	1.08	4.72	8.76	1.08

*Neutron energies are as follows: thermal, $E < 0.4$ ev; resonance, $0.4 \text{ ev} < E < 0.1 \text{ Mev}$; fast, $E > 0.1 \text{ Mev}$.

molybdenum baffles. The baffles were spaced by 1/4-in.-square heater support posts. The assembly (including baffles, heater support posts, and all instrumentation leads) is shown in Figure 6. The heaters (not shown) used for temperature control were 1/8-in.-diameter niobium-sheathed MgO-insulated Nichrome and were wrapped around the heater support posts and secured with tantalum wire. Niobium foil baffles were then wrapped around the heaters and secured in position with molybdenum wire. Proportional controllers were used for temperature control.

Sixty-six thermocouples were used to monitor component temperatures. Eighteen sheathed thermocouples were used to monitor internal component temperatures. The remainder were used to monitor the external surfaces of the various components. Coil temperatures were determined by measuring the change in coil resistance and referring to a graph of coil resistance as a function of temperature.

The only temperature control problem occurred in the lower assembly. It was found that heaters in the limit switch zone influenced the temperature of the lower position sensor. In order to keep the temperature of the position sensor below its maximum, the limit switch temperatures were limited to 900°F while the reactor was operating. It was originally planned to maintain the limit switches at 1000°F. The 1000°F temperature was maintained during reactor "down" periods.

Average component temperatures are summarized in Table 3.

3. Vacuum

The pumping unit at the BRR consisted of (1) two 400-liter/sec triode-type ion pumps, (2) a 7500-liter/sec titanium sublimation booster pump, and (3) a Roots-type compound blower with a complete cold-wall liquid nitrogen trap. The system was normally evacuated to 10^{-4} torr with the Roots blower and its mechanical backup pump. The ion pump and sublimator were started and the blower was valved out of the system. Gas analyzer measurements above the blower cold-trap made prior to the start of the test indicated that no hydrocarbons were being introduced into the system. The sublimator was used only intermittently after the initial high out-gassing period. After the initial period, it was found that one ion pump could handle the gas load of the entire system. The vacuum history of the test is shown in Figure 7.

TABLE 3
AVERAGE COMPONENT TEMPERATURES

Location	Temperature (°F)	
	Upper Assembly	Lower Assembly
Position Sensor, Coil*	800 ± 10	870 ^{+ 0} - 30
Outer Case	760 ± 15	750 ± 20
Actuator, Front Bearing	925 ± 15	925 ± 20
Rotor	955 ± 10	1010 ± 10
Stator	955 ± 25	910 ± 20
Stator Coil*	1000 ^{+ 0} - 20	1000 ± 20
Brake, Coil*	1000 ± 20	1000 ± 20
Inner Wall	950 ± 10	940 ± 15
Outer Case	920 ± 15	935 ± 20
Limit Switches	—	900 ± 10†

*Indicates temperatures calculated from measurements of coil resistance.

†Limit switches operated at 980 ± 20 during reactor "down" periods.

Figure 7. Vacuum History

IV. COMPONENT PERFORMANCE MEASUREMENTS

Each actuator position sensor assembly completed 61 functional tests at operating temperature. The upper actuator was operated 40 steps clockwise, 80 steps counterclockwise, and finally 40 steps clockwise during each functional test, rotating the position sensor through a 144-deg arc. The lower actuator was operated in a similar manner through a 245-deg arc. The additional rotation was needed to actuate the limit switches. The position sensor demodulator output was recorded at each 4-step interval. The actuator was operated with 1.60 amp to each stator phase. The current to energize and de-energize the actuator brake was determined during each functional test.

Each component in the test assembly was instrumented with two wires attached to each coil terminal. With this arrangement, the resistance in the circuits up to the coil was measured and subtracted from the overall resistance of the circuit. The four-wire bridge circuit was used to measure coil resistances of the following:

- 1) Actuator phases (all four)
- 2) Brake coil
- 3) Position sensor (primary and two secondaries)
- 4) Magnetic pickup.

These measurements were made for the purpose of calculating coil temperatures and not to monitor coil resistance changes. No gross changes in coil resistance were observed.

Contact resistance of each limit switch was also determined using a four-wire bridge circuit.

Insulation resistance measurements were made at 50 volts dc on the following:

- 1) Actuator, coil common to ground
- 2) Brake to ground
- 3) Position sensor, primary to ground
- 4) Position sensor, each secondary to ground
- 5) Position sensor, primary to each secondary

- 6) Magnetic pickup to ground
- 7) Limit switch, each pin to ground
- 8) Limit switch, pin-to-pin
- 9) Dummy leads.

V. DISCUSSION OF RESULTS

Table 4 summarizes the pre- and post-test insulation resistances. Detailed graphs of the significant resistances are included with the text discussing the performance. Visual examination of the components in the hot cell after the test indicated no significant change due to the test.

A. CONTROL DRUM ACTUATORS

Figure 8 shows the phase coil insulation resistance history of both upper and lower actuators. The indicated insulation resistance values are below normal, and degraded continuously during the test. Evaluation of these low resistances indicates that these components were contaminated with organic materials either during fabrication or during pre-irradiation vacuum testing at AI. The resistances were measured to the common of the four actuator coils and are therefore lower than individual coil insulation resistances measured during manufacture. The pre-irradiation testing was carried out in diffusion pumped vacuum systems. Prior testing at AI has shown that when an insulating material is exposed to organic contaminants such as may be present in a vacuum environment maintained by an inadequately trapped diffusion pump, the organic material decomposes into a conducting carbon film when heated in vacuo above 800°F. To determine the possible insulation resistance change of the electrical cables leading to the actuators, identical dummy cables were incorporated into the test assembly and monitored throughout the test. Since insulation resistance of these dummy cables remained high, as shown in Figure 9, it was concluded that the low insulation resistance conditions were within the actuator.

As final confirmation of the cause of the degradation, air was bled into the test chamber at the conclusion of the irradiation test while components were at test temperatures. Rapid recovery of insulation resistance was experienced, indicating that the conducting carbon film was removed by oxidation. This insulation resistance recovery is shown in Figure 10.

Both actuators were the first two of the production run, and were bench-tested previously in an ordinary diffusion pumped vacuum environment. Subsequent assemblies were bench-tested in diffusion pumped vacuum systems with operating procedures that minimized oil contamination. Two of these units were operated

TABLE 4
SUMMARY OF COIL INSULATION RESISTANCES
PRE- AND POST-TEST

Component	Insulation Resistance (ohms)				
	Pre-irradiation		Post-irradiation*		
	Ambient Temperature	Operating Temperature	Operating Temperature Before Recovery	Operating Temperature After Recovery	Ambient Temperature
Upper Assembly					
Position Sensor					
Coil to coil	5×10^6	8×10^7	3×10^7	1×10^7	6×10^8
Coil to ground	7×10^7	1.5×10^8	2.2×10^7	3×10^8	7×10^8
Actuator to ground	9×10^6	5×10^3	1.1×10^3	2.5×10^7	3.5×10^8
Brake to ground	8×10^6	2×10^5	3.9×10^5	1.5×10^7	6×10^8
Magnetic pickup to ground	8×10^6	1×10^5	4×10^4	1×10^5	6×10^8
Lower Assembly					
Position Sensor					
Coil to coil	3×10^8	1.5×10^6	4×10^4	8×10^6	6×10^8
Coil to ground	3×10^8	1.5×10^6	2.9×10^4	2.0×10^7	7×10^8
Actuator to ground	3×10^6	1×10^3	2.4×10^2	1.8×10^7	3×10^8
Brake to ground	1×10^7	5×10^6	7.8×10^5	2.7×10^7	5×10^8
Magnetic pickup to ground	2×10^6	1×10^5	1.5×10^5	1.5×10^5	5.5×10^8
Limit Switch 1					
Open to common	1×10^8	$1 \times 10^{7\dagger}$	1.3×10^7	-	5×10^8
Open to ground	1×10^8	1×10^7	7×10^6	-	5×10^8
Limit Switch 2					
Open to common	1×10^8	$8 \times 10^{5\dagger}$	8.8×10^6	-	5×10^8
Open to ground	2×10^8	7×10^6	7×10^6	-	5×10^8

*Recovery was accomplished by admitting air into the test to burn carbon deposits away.

†Temperatures were higher during out-of-pile period than during the in-pile period.

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Figure 8. Actuator Insulation Resistance History

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Figure 9. Insulation Resistance History of Dummy Cables

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Figure 10. Insulation Resistance Recovery Test

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out-of-pile under very similar temperature endurance conditions in a diffusion pumped vacuum, and at the end of 3000 hr the insulation resistance exceeded 50,000 ohms. Because of the rapid recovery of insulation resistance and the results of the out-of-pile tests, it is concluded that the low insulation resistance was not attributable to radiation effects.

The actuator brake coil insulation resistance histories are shown in Figure 11. Both brake coils were below the 90-megohm resistance at 70°F but met the 50,000-ohm operating temperature insulation resistance requirement before "burn-off" at the end of the irradiation test.

Figures 12 and 13 show the currents required to "pull-in" and "release" the brake, as determined at various times during the experiment. The current required for the brake to "pull-in" is well below the 0.9-amp requirement at the 1075°F operating temperature. The uniformity of the "pull-in" and "release" current indicates that no measurable seizing or adhesion of the brake surfaces occurred during the test, and that no measurable change of brake spring rate occurred during the test.

The 20 oz-in. torque load represented 3 oz-in. higher than the margin acceleration and drive requirement of 17 oz-in. for an S8DS control drum. The actuator stepped against this restraining torque successfully with 1.6 amps applied during all testing, even when the insulation resistance had dropped to 240 ohms on the lower actuator.

B. POSITION SENSORS

Insulation resistance of the position sensors was monitored throughout the experiment between each coil and ground and between coils. The requirement is 10 megohms at 77°F, and 1 megohm at 800°F. Measurements taken on the upper position sensor are shown in Figures 14 and 15. Only minor degradation of insulation resistance was experienced by this component. The dummy cable lead to this device did not show any degradation.

Insulation resistance of the lower position sensor degraded markedly as shown in Figures 16 and 17. During the post-test bakeout, insulation resistance of both upper and lower position sensors recovered completely to their original values (Table 4), indicating that the low resistance was due to contamination.

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Figure 11. Actuator Brake Coil Insulation Resistance History

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Figure 12. Lower Actuator Brake Test

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Figure 13. Upper Actuator Brake Test

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Figure 14. Upper Position Sensor:
Insulation Resistance to Ground

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Figure 15. Upper Position Sensor: Insulation Resistance Between Coils

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Figure 16. Lower Position Sensor: Insulation Resistance to Ground

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Figure 17. Lower Position Sensor: Insulation Resistance Between Coils

As mentioned previously, the output of the position sensor demodulator was recorded at 7.2 deg intervals over the full 144 deg travel of position sensor. The output of the position sensor demodulator is plotted vs rotor position in Figures 18 and 19. The pre-test data were taken during a functional test before the assembly was installed in-pile. The post-test data were taken after irradiation was complete, and the assembly had been moved out-of-pile. All data were taken with the components at operating temperature. Figures 20 and 21 show the demodulator output during the test at constant sensor position. The 50.4 deg rotor position chosen as a reference location was picked arbitrarily.

The position sensing requirements are a repeatability within 1.5 deg at room temperature and 2 deg at vacuum, and a temperature and linearity of 2% over a 144 deg angular movement. The upper position sensor met this criteria (0.7 deg repeatability and 1.08% linearity over 144 deg movement) as shown in Figures 18 and 20. The lower position sensor met the linearity requirement (1.90% over 144 deg) but the repeatability was exceeded (2.8 deg was observed). It is felt that the poor repeatability was not caused by radiation, or both sensors would have shown the same effect. When the test assembly was first brought up to temperature and returned back to room temperature, an "open" in one coil on the lower position sensor was noted. This "open" was not recorded on any subsequent measurements. The conditions responsible for this "open" may have affected repeatability. More probably, the difference of repeatability between the two units is attributed to difference in the rotor bearing clearances. The lower sensor rotor bearing clearances were 0.0010 to 0.0012 in. as compared to 0.0006 to 0.0008 in. of the upper sensor bearing. However, the sensor was too radioactive to examine, so a definite cause cannot be determined.

C. LIMIT SWITCHES

Insulation resistance between pins and from each pin to ground on each limit switch was measured periodically. Results are shown in Figures 22 and 23 and Table 4. Contact resistance of the switches was also measured, and the data are shown in Figure 24. No deviation from the specification requirements for contact resistance (2 ohms maximum) or insulation resistance (10 megohms at 70°F and 1 megohm at 1000°F) was observed during the test. The switches were actuated 122 times while at test temperature, vacuum, and radiation.

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Figure 18. Demodulator Output of Upper Position Sensor vs Rotor Position During Pre- and Post-irradiation Functional Tests

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Figure 19. Demodulator Output of Lower Position Sensor vs Rotor Position During Pre- and Post-irradiation Functional Time

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Figure 20. Upper Position Sensor Output vs Elapsed Time at Temperature

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Figure 21. Lower Position Sensor Output vs Elapsed Time at Temperature

Figure 22. Insulation Resistance of Limit Switch No. 1

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Figure 23. Insulation Resistance of Limit Switch No. 2

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Figure 24. Contact Resistance of Limit Switches

Force-deflection calibration of the actuating plunger was made on each switch prior to the test. After the irradiation test, hot-cell calibration of the actuating plunger was repeated. Three deflection determinations were made at 1-oz intervals from 13 to 47 oz. The calibration curves are shown in Figure 25. The switching point of each of the switches which was monitored throughout the test did not change, and remained within the design limit; therefore, the post-test calibration curves were normalized to the pre-test switching points. This procedure facilitates evaluation of spring relaxation, which was the primary objective of performing the calibrations. The apparent load loss of the pre-travel and over-travel springs in Switch 1 was about 13% and 17%, respectively; while in Switch 2 the losses were 8% and 15%, respectively.

a. Limit Switch No. 1

b. Limit Switch No. 2

Figure 25. Force-Deflection Measurements at Room Temperature

VI. CONCLUSIONS

This experiment has demonstrated the successful operation of the S8DS control drum drive actuators, position sensors, and limit switches in a combined vacuum, high temperature, and reactor radiation environment. No effects on the components are directly attributable to the radiation environment.

The actuators stepped against a restraining torque of 20 oz-in. which is 3 oz-in. greater than the maximum drum stepping requirement for the S8DS system. Very low insulation resistance (240 ohms) in one actuator did not affect its operation. The effect of organic contamination on insulation, and a method of removal, was shown during the test. The actuator brake showed no high vacuum-high temperature adhesion effects. It is therefore concluded that the S8DS actuators are satisfactory for use in the S8DS nuclear test.

The upper position sensor met all the sensing requirements during the test; however, the lower sensor failed to meet the repeatability requirement although the cause cannot be definitely determined. It is recommended that the S8DS position sensors be used for S8DS testing.

All performance parameters of the limit switches that were monitored remained within the specification requirements during the test. Therefore, the limit switches are also recommended for use on the S8DS system test.