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AUGUST-OCTOBER 1965
(Title Unclassified)

AEC Research and Development Report

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SNAP PROGRAM
M-3679 (41st Ed.)

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AUGUST-OCTOBER 1965

(Title Unclassified)

D. G. MASON

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The previous SNAP 8 progress report was "SNAP 8 Progress Report, May-July 1965," D. G. Mason, NAA-SR-11492 (CRD), issued September 30, 1965.

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I. PROGRAM OBJECTIVES

The objectives of the SNAP 8 reactor program are to assemble and test the 600-kwt, 1300°F SNAP 8 reactor and to continue the development of technology to provide a reactor capability at thermal power levels up to approximately 1 Mwt for space electric power applications. The SNAP 8 reactor program is being performed for the Atomic Energy Commission (AEC). The performance objectives of the ref-

erence design SNAP 8 reactor are summarized in Table 1.

TABLE 1
SNAP 8 REACTOR PERFORMANCE
OBJECTIVES

Thermal Power	600 kwt
NaK Outlet Temperature	1300°F
Reactor Operating Period	10,000 hours
Reliability	96 to 99%

II. PROGRESS SUMMARY

A. FUEL DEVELOPMENT

The NAA-115-1, NAA-115-2 and NAA-117-1 irradiation tests continue satisfactorily at Hanford. Preparations were completed for the receipt of the NAA-115-1 irradiation capsule at the AI hot laboratory.

A group of seven S8DS fuel elements were assembled using improved tube chromizing and cleaning processes. These elements have successfully completed low level vibration tests, twenty-five ramp heats, and are now undergoing endurance testing. The performance of these elements has been excellent. The average hydrogen loss rate for the elements has increased from 0.33 to 0.43 cc(STP)/hr at 1400°F during testing to date.

B. COMPONENT DEVELOPMENT

The HF-10 irradiation experiment was inserted into the Battelle Memorial Institute reactor. This capsule contains two S8DS actuators, two position sensors, and two limit switches. Each component is maintained at its S8DS design temperature and vacuum. All components are performing satisfactorily.

Three S8DS actuators and one scram mechanism have completed over 4200 hours of endurance testing at rated S8DS temperature and vacuum. The scram unit has also simulated over 400 scrams and has been subjected to 15 thermal cycles. A set of S8DS bearings has satisfactorily completed over 1200 hours at rated S8DS temperature and vacuum.

C. SYSTEM DEVELOPMENT

1. SNAP 8 Experimental Reactor (S8ER)

All S8ER fuel elements have been visually inspected at the AI Hot Laboratory. The 211 fuel elements have completed all planned phases of the screening examination which include dimensional measurements, hydrogen distribution measurements, weighing, and gamma scan. Cladding cracks were found in 170 of these fuel elements.

Detailed examination of 22 S8ER fuel elements was initiated at the AI hot laboratory. Eleven elements have been de-clad by the standard Elox process to obtain metallography samples, burnup samples, hydrogen distribution samples, and fuel rod dimensions. One

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element has been disassembled using a dry Elox process to investigate the apparent reaction between the fuel and the hydrogen barrier. Five elements have been sectioned radially to investigate any cladding/ceramic/fuel interaction. Five elements have had a 10-inch section cut from the center portion of the element for cladding tensile testing.

2. SNAP 8 Ground Prototype (S8DS)

Six actuators have successfully completed acceptance tests and three position sensors are presently on test.

The S8DS controller, two scram kits, and 19 limit switches were successfully acceptance tested during October.

Installation of electrical wiring and equipment in the Ground Prototype Test Facility (Building 059) has been completed by the contractor. Work has been initiated on the final instrumentation wiring in the facility.

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III. REFERENCE DESIGN

The SNAP 8 nuclear system for instrument-rated applications (Figure 1) consists of a shielded compact nuclear reactor moderated by zirconium hydride and cooled by liquid NaK-78. The reactor is controlled by movable beryllium reflectors which, by their position, control the amount of leakage flux. Each major assembly of the instrument-rated SNAP 8 nuclear system is described in the following paragraphs. Table 2 lists the detailed characteristics of the instrument-rated SNAP 8 nuclear system. A weight summary of the instrument-rated nuclear system is given in Table 3, and the environmental criteria are summarized in Table 4.

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Figure 1. SNAP 8 Nuclear System

The design reliability goal for the instrument-rated nuclear system has been tentatively established at 96.3%.

A. FUEL ELEMENTS

The SNAP 8 reactor core contains 211 fuel elements made of Zr - 10.5 wt % U alloy hydrided to a hydrogen content of 6×10^{22} hydrogen atoms/cc of $(U-Zr)H_x$. The uranium is 93% enriched. The elements are clad in 10-mil-thick Hastelloy-N tubing, coated internally with a hydrogen permeation barrier. The active length of the fuel element is 16.825 in. Other dimensions and characteristics are listed in Table 2.

B. CORE VESSEL AND INTERNALS (LESS FUEL ELEMENTS)

The core vessel is 0.105-in.-thick stainless steel. The core vessel contains an upper grid plate of 316 SS, a lower grid plate of Hastelloy-C, a coolant baffle plate of 316 SS, internal BeO reflectors clad in 316 SS, and the 211 fuel elements previously described.

C. INSTRUMENTATION AND REFLECTOR ASSEMBLIES

The beryllium control reflector assembly is made in two halves so that it forms a hollow right-circular cylinder completely surrounding the active core length. The beryllium reflector is a nominal 3 inches thick, with the ability to shim both positively and negatively 1 in. Each reflector drum is driven by its own drive mechanism. Three reflector drums are used as startup drums and are driven by springs. The other three reflector drums are used as control drums and are driven by long-term bidirectional control-drum actuators. A startup programmer and controller are provided to achieve proper operational sequence of the drums. A platinum resistance temperature sensor is used to measure the coolant outlet temperature.

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TABLE 2
SNAP 8 REFERENCE INSTRUMENT-RATED NUCLEAR
SYSTEM CHARACTERISTICS

Reactor Design			
Fuel Elements		Nuclear Parameters	
Number	211	Average thermal neutron flux <1 ev, n/cm ² -sec	3 x 10 ¹²
Fuel alloy, wt % U in Zr	10.5	Median fission energy, ev	0.21
Uranium enrichment, at. % U ²³⁵	93.15	Mean prompt neutron lifetime, μ-sec	8.4
Degree of hydriding, N _H , 10 ²² a/cm ³	6.05	Uranium loading, kg U ²³⁵	7.65
Fuel rod diameter, in.	0.530	Hydrogen reactivity worth, %Δk/k per %ΔH/H	0.50
Active fuel length, in.	16.825	Volume fractions in core	
Fuel element length, in.	17.145	Fuel	0.782
Cladding material	Hast-N	Cladding	0.061
Cladding ID, in.	0.540	NaK	0.123
Cladding thickness, in.	0.010	Ceramic	0.013
Ceramic barrier material	SCB	Void	0.021
Ceramic barrier thickness, in.	0.002	Radial peak to average power	1.22
Diametral hydrogen gap, in.	0.006	Axial peak to average power	1.44
Source		Average power density, watts/cc	36.6
Type	Po-Be	Reliability Goals, %	
Strength, curies	0.1	Overall	96.85
Location	top head of vessel	Core assembly	98.96
Internal Reflectors		Reflector assembly	98.50
Composition	BeO	Shield assembly	99.97
Cladding material	316 SS	Safety assembly	99.44
Cladding thickness, in.	0.030	Cumulative Probability of Success	
Inlet Plenum Grid Plate		Through launch	99.74
Material	Hast-C	Through startup	98.87
Thickness, in.	0.650	Through 10,000 hours	97.23
Diameter, in.	9.186	Complete mission	96.85
Number of coolant holes	372	Nonpuncture probability	99.9
Diameter of coolant holes, in.	0.156	Control System Parameters	
Pitch of coolant holes, in.	0.570	Single control drum worth, \$	3.90
Outlet Plenum Grid Plate		Full-in drum position, degrees	0
Material	316 SS	Full-out drum position, degrees	154
Thickness, in.	0.850	Drum movement per step, degrees	0.26
Number of coolant holes	372	Maximum drum rotation rates, degrees/sec	
Diameter of coolant holes, in.	0.156	Startup drums (simultaneous motion)	0.086
Pitch of coolant holes, in.	0.570	Control drums	0.053
Coolant		Maximum differential drum worth, \$/degree (nominal shim)	7.0
Material	NaK-78	Kinetic Parameters	
Melting point, °F	12	Number of delayed neutron groups	6
Core Vessel		Decay constants, sec ⁻¹	
Material	316 SS	λ ₁	0.0124
Internal diameter, in.	9.214	λ ₂	0.0305
Thickness, in.	0.105	λ ₃	0.111
Length, in.	26.24	λ ₄	0.301
Distance between grid plates, in.	17.224	λ ₅	1.13
Reflector Control Elements		λ ₆	3.0
Material	Be	Effective delayed neutron fraction	0.0080
Number of startup drums	3	Group delayed fractions	
Number of long-term control drums	3	α ₁	0.0329
Total number of drums	6	α ₂	0.2194
Radius of curvature of drums, in.	4.5	α ₃	0.1960
Nominal thickness of drums, in.	3.125	α ₄	0.3947
Shimming capability, in.	+1.5, -1.0	α ₅	0.1150
Envelope, drums full out, in.	27.6	α ₆	0.0419
Overall length, in.	18.5	Transport delay times (@ 35 kwe), sec	
Drum length, in.	15.375	Nuclear system to boiler	1.0
Reactor Parameters		Boiler	6.8
Design Operating Conditions		Boiler to nuclear system	4.5
Reactor thermal power, kw	600	Nuclear system	1.7
Net electrical power, kwe	35(@ 470 kw)	Typical Shield Parameters	
Coolant inlet temperature, °F	1100	Instrumented Payload Dimensions	
Coolant outlet temperature, °F	1300	Diameter, ft	20
Coolant flow rate, lb/sec	13.6	Axial distance from reactor core center, ft	40
Operating pressure, psia	45	Shield Materials	
Core pressure drop, psi	4.8 (@ 600 kw)	Cladding	347 SS
Maximum hot spot fuel temperature °F	1520	Gamma	W
Maximum hot spot cladding temperature, °F	1430	Neutron	LiH
Operating lifetime, hr	10,000	Shield Dimensions	
Peak heat flux, Btu/hr-ft ²	~100,000	Overall shield length, in.	34.3
NS pressure drop, psi	<8(@ 600 kw)	Neutron shield thickness, in.	33.3
Reactivity Requirements, \$		Gamma shield thickness, in.	1.0
Xenon	-1.05	Maximum diameter of conical shield, in.	51.5
Samarium buildup	-1.02	Minimum diameter of conical shield, in.	39.2
Fission product poison	-1.17	Radiation Levels Due to Reactor Sources	
U ²³⁵ burnup	-0.66	Fast neutron dose at payload, nvt	1 x 10 ¹¹
Temperature and power defect	-2.15	Gamma dose at payload, rads (C)	1 x 10 ⁶
Hydrogen redistribution	-0.55	Shield Assembly Weight, lb	
Hydrogen loss	-2.00	Neutron shield	1365
Contingency	-2.40	Gamma shield	115
Cold Clean Excess Reactivity	+8.00	Shield vessel and structure	450
Samarium Burnout	+3.00	Total shield assembly weight without armor	1930
Total Control Drum Worth	\$21.06		
Shutdown Margin	-13.06		
Temperature Coefficients, \$/°F (at design power level)			
Spectrum	-0.01		
Axial expansion	-0.048		
Upper grid plate	-0.026		
Lower grid plate	-0.019		
Reflector (prompt, lower plenum)	-0.04		
Reflector (prompt, upper plenum)	-0.04		
Total isothermal (%1200°F)	-0.20		
Total isothermal (3 room temperature)	-0.15		

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TABLE 3
SNAP 8 NUCLEAR SYSTEM WEIGHT SUMMARY

System Component	Quantity	Weight Per Item* (lb)	Total Weight (lb)	Center of Gravity [†] (in.)		
				X	Y	Z
Core Assembly	1	-	310.3	26.0	0.0	0.0
Core vessel	1	45.2	45.7	24.5	0.0	↑
Outlet plenum grid plate	1	5.9	5.9	16.1	0.0	
Fuel elements	211	0.8	193.9	25.1	0.0	
Internal reflectors	42	-	12.0	25.0	0.0	
Inlet plenum grid plate	1	6.5	6.5	33.4	0.0	
Flow baffle plate	1	7.0	7.0	34.6	0.0	
Inlet NaK pipe (16 in. long)	1	1.8	1.8	40.0	13.5	
Outlet NaK pipe (54 in. long)	1	8.4	8.4	25.0	10.0	
NaK in vessel	-	18.7	18.7	26.9	0.0	
NaK in pipe	-	10.4	10.4	27.9	11.2	
Reflector Assembly	1	-	284.6	22.8	+ 0.1	
Control drum actuators	3	20.0	60.0	11.5	0.0	
Startup drum drives	3	0.8	2.4	14.0	0.0	
Reentry actuator assembly	1	6.0	6.0	16.5	-11.2	
Upper drum support assemblies	6	2.0	12.0	16.5	0.0	
Fixed external reflectors	2	22.5	45.0	25.0	0.0	
End-of-life shutdown actuator	1	1.8	1.8	16.5	11.2	
Control and startup drums	6	19.9	119.5	25.0	0.0	
Shear and load lugs	8	1.0	8.0	31.2	0.0	
Drum release actuators	6	0.6	3.6	33.5	0.0	
Lower drum support assemblies	6	2.0	12.0	33.8	0.0	
Reflector ejection springs	4	1.0	4.0	36.0	0.0	
Drum position indicators	3	0.5	1.5	36.4	0.0	
Drum key lock brackets	4	0.9	3.6	15.3	0.0	
Miscellaneous brackets and fittings	-	-	5.2	34.9	0.0	
Shield Assembly	1	1930	1930	58.1	+ 0.3	
Miscellaneous						↓
Supplemental reflector drum shims	6	6.2	37.1	25.0	0.0	
Environmental cover	1	~65	~65	~44	0.0	
Payload instrumentation	-	~17	~17	-	-	
Diagnostic instrumentation	-	~50	~50	-	-	
Interconnecting cables	-	~20	~20	~44	-	-

*Weight expressed to the nearest 0.1 lb

†X axis — is the centerline of the nuclear system. X = 0 is a point 25.000 in. forward of the midpoint between the upper and lower grid plates. The positive direction is toward the nuclear system.

Y axis — is perpendicular to the X axis with the positive direction being toward the side of the reactor where the coolant outlet pipe crosses over the side of the reactor.

Z axis — is orthogonal to the X and Y axes with the positive direction being 90° clockwise from the positive Y axis when viewing the nuclear system from the reactor end.

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TABLE 4
SNAP 8 NUCLEAR SYSTEM ENVIRONMENTAL CRITERIA
(Page 1 of 2)

Environment	Ground Handling and Prelaunch*	Launch†	Orbit§															
1. Pressure	External pressures: sea level to 50,000 ft with maximum change ±1.25 psi/min.	External static pressure envelope as a function of time. (To be determined)	External pressure: 10 ⁻¹² mm Hg															
2. Temperature	+50 to +160°F	-	-															
3. Humidity	a. Protected during shipment and storage (RH <70%)* b. During vehicle integration: 6 hr at 65% RH and 106 °F; 6 hr of decreasing temperature to 91 °F and increasing RH to 100%; 8 hr of decreasing temperature to 81 °F with release of 4.4 grains H ₂ O/ft ³ ; 4 hr of increasing temperature to 106 °F and decreasing RH to 50%	-	-															
4. Rain	a. Protected during shipment and storage b. During vehicle integration: Anticipated precipitation <table><tr><td>Rate (in. /hr)</td><td>Amount (in.)</td><td>Time</td></tr><tr><td>0.6</td><td>7.1</td><td>12 hr</td></tr><tr><td>6</td><td>0.5</td><td>5 min</td></tr><tr><td>12</td><td>0.2</td><td>1 min</td></tr><tr><td>0.34</td><td>4.0</td><td>12 hr</td></tr></table>	Rate (in. /hr)	Amount (in.)	Time	0.6	7.1	12 hr	6	0.5	5 min	12	0.2	1 min	0.34	4.0	12 hr	-	-
Rate (in. /hr)	Amount (in.)	Time																
0.6	7.1	12 hr																
6	0.5	5 min																
12	0.2	1 min																
0.34	4.0	12 hr																
5. Sand and dust	a. Protected during shipment and storage b. Applicable components tested with 140-mesh silica flour for 3 hr at 77°F and RH <30%; sand and dust density, 0.1 to 0.25 grams/ft ³ , with air velocity = 2500±500 ft/min	-	-															
6. Salt spray	a. Protected during shipment and storage b. Applicable components tested to demonstrate ability to withstand exposure to salt spray for 6 wk as experienced at coastal regions of continental U.S.A.	-	-															
7. Fungus	Applicable components tested per MIL-E-52720(ASG), Fungus Resistance Tests, Procedure 1.	-	-															
8. Shock	Drop of 18 in. measured at either a corner or a surface, onto a concrete surface.	System Three shocks of 18 g's in each of 3 mutually perpendicular axes (18 total) of one of the following pulses: a. Triangular pulse 10 msec b. Half-sine pulse 8 msec c. Rectangular pulse 5 msec Component: Three shocks of 35 g's in each of 3 mutually perpendicular axes (18 total) of one of the following pulses: a. Triangular pulse 10 msec b. Half-sine pulse 8 msec c. Rectangular pulse 5 msec	Nonoperating††: capable of withstanding 3-g shocks on each of 3 mutually perpendicular axes at one of the following wave forms: a. Triangular pulse 10 msec b. Half-sine wave pulse 8 msec c. Rectangular pulse 5 msec Operating: withstand 3-g peak, half-sine wave pulse of one msec at mounting interface															

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TABLE 4
SNAP 8 NUCLEAR SYSTEM ENVIRONMENTAL CRITERIA
(Page 2 of 2)

Environment	Ground Handling and Prelaunch [‡]	Launch [†]	Orbit [§]
9. Vibration	Sweep applied to transportation container on 3(30-min log) mutually perpendicular axes: 2 to 5 cps at 1 in. double amplitude; 5 to 27.5 cps at 2-g peak; 27.5 to 43.5 cps at 0.0517 in. double amplitude; 43.5 to 500 cps at 5-g peak; then a 5-min dwell at each resonant frequency noted at above amplitude	<p>System</p> <p>Sweep from 5 to 16 cps at 0.368 in. double amplitude and 16 to 2000 cps at 5-g peak on each of 3 mutually perpendicular axes; then 5-min dwell at each major resonant frequency at the above amplitude</p> <p>Component</p> <p>16 to 100 cps at 6-g peak; 100 to 180 cps at 0.0118 in. double amplitude; 180 to 2000 cps at 19-g peak; then dwell at 1/2 above amplitude for 5 min at each major resonant frequency</p> <p>Random Vibration - Components</p> <p>A random vibration sweep test over a frequency interval of 20 to 2000 cps for 5 min in each of 3 mutually perpendicular axes according to the following schedule:</p> <p>20 to 200 cps at +2 db/oct 200 to 700 cps at 0.64 g²/cps 700 to 900 cps at -17.5 db/oct 900 to 2000 cps at 0.15 g²/cps</p>	Capable of withstanding vibrations of 0.25-g peak over a frequency of 5 to 2000 cps for 5 min at the NS mounting interface
10. Wind	Withstand steady-state wind force of 54 mph with wedge-shaped gusts of 75 mph	-	-
11. Storage life	Two years (except source)	-	-
12. Radio frequency generation and interference	-	Designed and tested to MIL-STD-826 (USAF) dated 20 January 1964	Designed and tested to MIL-STD-826 (USAF) dated 20 January 1964
13. Acoustic noise	-	Total integrated sound pressure level of 148 db, Re 0.0002 microbar over a specific frequency spectrum	-
14. Acceleration	-	Longitudinal axis: +7 g for 5 min, -3 g for 5 min; lateral and normal axes: ±4.5 g for 5 min	Operating: +1 g along axis of symmetry and ±1/4 g radially including rotational effects Nonoperating:†† +3-1/2 g along longitudinal axis in combination with ±1 g on any lateral axis for a period of time less than 5 min
15. Magnetic fields	-	-	To be determined
16. Gravitational fields	-	-	To be determined
17. External radiation	-	-	To be determined

*Environment to which the nuclear system may be subjected without any detrimental effects during shipment from Atomics International up to the time of encapsulation in the launch vehicle nose cone

†Environment to which the nuclear system may be subjected without any detrimental effects after exposure to the ground handling and prelaunch environment up to the time of separation from the launch vehicle

§Environment to which the nuclear system may be subjected without any detrimental effects after exposure to the launch environment

**RH = Relative humidity

††Nonoperating: Defined as prohibiting operation of the reflector-control system; i.e., control drums are held stationary

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D. SHIELD

A typical neutron shadow shield designed to limit the dose at the payload is in the shape of a truncated cone whose cone angle completely hides the payload from the reactor assembly. The neutron shield is made of lithium hydride (LiH) cast in a stainless-steel container. Between the neutron shield and the reactor assembly is a circular plate of tungsten designed to limit the gamma dose at the payload. The design parameters for a typical 600-kwt shield are given in Table 2.

E. SAFETY SYSTEM

The safety system includes a reentry actuator, reflector ejection springs, a destruct charge, an end-of-life scram actuator, a telemetry scram actuator, a reflector unlocking actuator, and associated circuitry. In addition, void filler blocks and a drum lockout system are furnished as part of the ground handling safety equipment.

The reentry actuator is designed to hold the reflector assembly in place at the top of the core vessel. The actuator is designed and located so that it will be melted by reentry heat. Heating of this actuator allows the reflector ejection springs to remove the reflector assembly from the vicinity of the core vessel.

The destruct charge is a shaped explosive charge surrounding the core vessel. It can be fired prior to reactor startup to preclude reactor criticality in the event of an unsuccessful launch. The destruct charge is optional and its use will be evaluated for each particular mission.

The reflector unlocking actuator is designed to hold the reflector assembly to the core vessel during launch. Thus, it is not necessary for the reentry actuator assembly to hold the reflector assembly under launch conditions.

The void filler blocks are neutron poison blocks designed to be slipped into the cavities in the stationary beryllium reflector normally occupied by the reflector drums when in their full-in position. The drum lockout system is a key-operated locking system designed to prevent reflector drum motion.

An environmental cover is supplied to protect the nuclear system from the natural environments such as rain, sand, and dust. The cover, using a side ejection concept, is supported from the base ring of the shield. View ports are provided for access to the pinpullers and the key locks. The cover is made of 5-mil aluminum honeycomb. The destruct charge, if used, is mounted on the cover and is ejected with the cover once startup is initiated.

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IV. FUEL ELEMENT DEVELOPMENT

A. INTRODUCTION AND SUMMARY

The objective of the fuel element program is to develop fuel elements for the 600-kwt SNAP 8 reactor that meet the following performance requirements:

1) A peak power density of the fuel of approximately 5.0 kwt/ft of fuel rod length at a peak central temperature of 1550°F. A peak fuel burnup of about 0.3 met. at. % in 10,000 hours.

2) Hydrogen loss from the fuel elements of less than 5% of that in the fuel alloy during 10,000 hours of reactor operation. The hydrogen barrier coating and closure seal must withstand thermal and mechanical checkout of the reactor, thermal shock during startup, and a peak cladding operation temperature of 1450°F. The fuel elements cladding also must resist corrosion in the NaK environment and maintain dimensional integrity over the life of the core.

3) A fuel element with 99% reliability at the 50% confidence level of meeting these performance goals. Redundant fuel elements are provided in the core so that failure of the hydrogen barrier in a few elements will still permit successful operation of the reactor.

Primary efforts were concentrated on the S8ER core examination, S8DS process improvement development, and the fuel element irradiation tests at Hanford.

The screening examination of the S8ER core was completed and detailed examination of selected fuel elements was begun at the Atomic International Hot Laboratory (AIHL). Results of the screening examination are presented in Section VI-D of this report.

Destructive evaluation of the S8ER nonnuclear performance test fuel elements continued in support of the S8ER core examination. Burst

tests were completed on 6 cladding tubes from fuel elements which had completed 10,000 hours of endurance testing. The average yield (0.2% offset) was at a hoop stress of 30,000 psi for tubes which had been on endurance test at 1300 and 1400°F. Resulting strain at rupture ranged from 0.2 to 4.1%, corresponding to hoop stresses of 27,000 to 41,000 psi. No correlation with endurance test temperature was seen.

Significant progress continued in the S8DS process improvement development efforts. The capability of the AI chromizing process to achieve a reproducible substrate thickness was demonstrated. Electron microprobe and x-ray diffraction studies of chromized cladding continued toward determining the substrate composition for optimum adherence of the SCB-1 hydrogen barrier. It was found that alpha-alumina was being entrapped in the chromized surface during the chromizing process. An improved sand-blasting process was developed for cleaning the chromized surface prior to coating. Adherence tests showed that ceramic coating adherence variability was minimized by the improved cleaning process. A group of 7 developmental S8DS fuel elements which were built using the improved processes performed significantly better than earlier SNAP 8 fuel elements after low-level vibration and ramp heat tests.

The NAA-115-1, NAA-115-2 and NAA-117-1 tests of sublength SNAP 8 fuel elements continued irradiation at Hanford. Preparations were completed for discharge from the reactor of NAA-115-1, the S8ER fuel element test.

B. FUEL ELEMENT DEVELOPMENT

1. Hydrogen Barrier

a. Coating Tests, S8DS Permeation Kinetics

Studies were continued on the fuel-coating reaction phenomenon to determine the pressure-temperature kinetics of the reaction for S8DS

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cladding assemblies. During the previous report period, a special sliding-fuel rod experiment was initiated in which H_2 permeation studies could be made on an SCB-1-coated S8DS cladding membrane without exposing the membrane to a machining operation or an oxidizing atmosphere during insertion or removal of a fuel rod. Temperature vs pressure data on the empty coated membrane (fuel in cold section of test fixture) showed a typical linear pressure dependence on permeation rate with an activation energy for diffusion of about 29 Kcal/mole.

As the fuel was inserted into the hot membrane (1400°F), the hydrogen permeation rate was observed to increase by 0.8 cc(STP)/hr. The hydrogen pressure in the membrane, both with and without fuel present, was controlled at 2 atm. Temperature vs pressure data on the SCB coating with the fuel in the hot zone showed a square-root-of-pressure relationship (Figure 2). The activation energy for diffusion was also reduced to a value of about 23 Kcal/mole.

This square-root-of-pressure behavior of permeation is only observed where a diatomic gas is dissociated into atoms at the permeating surface. It can be assumed, therefore, that some type of metallic or electrical-conducting film is being deposited on the surface of the SCB coating as a result of the proximity of the fuel.

All previous fuel-coating interaction studies showed that this reaction was completely reversible when the fuel rod was removed from the membrane assembly in an air environment. This experiment was specifically designed for removal of the fuel from the heated area in a hydrogen environment. When the fuel rod was withdrawn, no change in permeation rate was observed. Apparently, once the reaction product is formed, it is stable if maintained in a reducing atmosphere. Subsequent exposure of the inside of the membrane to air resulted in a hydrogen permeation rate decrease of 0.8 cc(STP)/hr at

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Figure 2. Hydrogen Permeation Rate vs Square Root of Pressure for SCB-Coated S8DS Cladding Tube Containing Fuel Rod

1400°F and 2 atm H_2 which shows that, indeed, the reaction product is not stable in air.

This test completed the planned test program for S8DS developmental cladding assemblies.

b. Coating Process Development

During this report period, the S8DS process improvement effort was primarily directed toward improving the uniformity of adherence of the SCB coating to the chromized Hastelloy-N substrate and improving the Atomics International chromizing process.

The reproducibility of the chromizing process developed in the previous reporting period was demonstrated on 25 tubes from 8 chromizing runs at 2135°F for 12 minutes. The results are presented in Table 5.

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TABLE 5
CHROMIZING RESULTS AT 2135°F
FOR 12 MINUTES

Experiment Number	Membrane Number	Diffusion Chrome Thickness (mils)
1	300-1	0.39
	473-2	0.40
	417-6	0.36
2	377-1	0.41
	261-1	0.40
	417-4	0.41
3	4068	0.32
	4069	0.30
	4070	0.39
4	3950	0.32
	3952	0.32
	3948	0.31
5	3948	0.31
	3957	0.29
	3958	0.31
6	4107	0.33
7	4055	0.37
	4060	0.35
	4065	0.35
	4066	0.50
	4094	0.34
8	4109	0.26
	4110	0.25
	4111	0.36
	4106	0.33
Average		0.347
Range		0.25 to 0.50

(1) Comparison of Various Vendors' Chromium Chlorides

Due to a potential shortage of chromium chloride from Vendor X, comparison experiments were conducted with material supplied by

another vendor. The average of 2 determinations resulted in a chrome layer thickness of 0.40 mil CrCl_3 from Vendor X and 0.45 mil CrCl_3 from Vendor Y. This difference in chromizing behavior is considered insignificant.

(2) Effects of Contamination on Adherence

In seeking the causes of the variable adherence of the ceramic coating to the chromized tubes, it became apparent that the surface condition of the tubes could be an important factor in this regard. The surface is characterized by irregular, rough areas located in a random manner over the entire surface of the chromized tubing (See Figure 3). Closer examination of these rough areas disclosed the presence of a finely divided nonmetallic material, which appeared to be imbedded in the surface. Some of the material was carefully scraped from the surface and subjected to an x-ray diffraction examination. The resulting x-ray diffraction pattern identified the contaminant as alpha-alumina. This particular modification of alumina is characterized by a hexagonal close-packed crystal structure and is formed at temperatures of approximately 1000°C (1832°F) and above.

The presence of alumina on the surface of the in-house chromized tubing was attributed to entrapment of some of the finely divided alumina used in the chromizing pack mix. A correlation between the amount of these particles and adherence values was established by conducting a particle count on three samples which exhibited poor, good, and intermediate values of adherence values, as shown in Table 6.

Experiments to avoid alumina inclusions by grinding the CrCl_3 to increase the homogeneity of the chromizing pack were not successful. The use of chromizing packs without alumina additions resulted on the other hand in an agglomeration and sintering of Cr grains to the chromized surfaces of the tubes.

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AS-CHROMIZED 17x

AS-SANDBLASTED 17x

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Figure 3. Typical Surface Conditions

TABLE 6
CORRELATION OF ADHERENCE WITH
ALUMINA PARTICLE COUNT

Adherence Index	Adherence		
	Poor 0	Inter- mediate 7	Good 77
Percentage of circumference covered by particles	29.5	19.6	5.3
Average particle size (mils)	0.165	0.179	0.083
Minimum particle size (mils)	0.029	0.045	0.029
Maximum particle size (mils)	0.510	0.500	0.275
Number of particles/inch	1,750	1,330	665

Three approaches to removing or avoiding alumina inclusions are presently under investigation. They are: (1) sandblasting the surface of the tubes with a specially designed nozzle which allows a controlled and efficient material removal from the inside walls of the tubes, (2) use of coarser grain sizes of alumina as a chromizing batch ingredient to decrease its chance for inclusion in the chromized layer, and (3) lowering of the chromizing temperature to reduce the rate of the chromized layer formation. The last approach has the additional advantages of making control of the chromizing process easier and decreasing the possibility of grain growth in the substrate.

Experiments were carried out employing a new internal nozzle sandblasting technique. A mechanism was constructed (see Figure 4) containing an internal-nozzle which directs a 360-degree stream of grit normal to the tube wall. Visual observations indicated that a much improved cleaning action was obtained from this method. Figure 3b shows a typical surface

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Figure 4. Internal Sandblasting Machine

condition after cleaning with the internal-nozzle. Screening tests were conducted to evaluate the effects of variation in the axial speed of the sandblast nozzle. Five sections of a chromized tube were sandblasted at 5 different speeds, from 5 to 1 in./min. The tube was then split longitudinally and examined. A screw-thread appearance was evident, corresponding to the thread of the drive mechanism. This condition was later eliminated by modification of the drive system.

One half of the split tube was subjected to an oxidation treatment equivalent to the SCB firing cycle. The dark green oxide formed on the inside of the tube was generally much more adherent than that formed on the outside (uncleaned) surface of the tube. The most adherent oxide was found toward the end of the tube in

areas representing nozzle speeds of one and two inches per minute. Spalling of the oxide was noted in the portion of the tube blasted at 5 in./min, indicating incomplete removal of the alumina spots.

As a result of this study, two in-house chromized tubes were sandblasted at a speed of 2 in./min, coated, dissected, and tested for adherence. The adherence exhibited by these two tubes was excellent and remarkably uniform as summarized in Table 7.

TABLE 7
ADHERENCE RESULTS ON TWO TUBES WHICH RECEIVED THE SANDBLAST TREATMENT

Specimen Location	Adherence Index	
	Tube No. 4196	Tube No. 4198
1 (Blind End)	35	77
2	35	77
3	49	77
4	42	63
5	49	56
6	49	35
7	42	35
8	42	35
9	42	26
10	42	28
11	35	32
EA (Open End)	42	24
Average	42	47

All of the adherence samples were characterized by a dark oxide substrate underneath the glass coating.

The first 4 or 5 inches of Tube No. 4198 were inadvertently sandblasted at a rate of approximately 1 in./min. This section was subsequently reblasted at 2 in./min, while the rest of the tube received the intended 2 in./min. Apparently the slower speed is more beneficial in improving adherence.

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On the basis of these observations, 7 tubes were sandblasted twice at the rate of 2 in./min (equivalent to 1 in./min), coated, assembled into elements, and subjected to developmental testing. The results of the testing to date are encouraging. The average hydrogen permeation rate from these elements showed only small increases after vibration and ramp heat tests. Details of these tests are discussed later in this report.

An experimental program was developed incorporating the three previously mentioned approaches to minimize the alumina inclusions. It consists of chromizing lots of 4 full-length, closed-end tubes and two 8-in.-long, open-end tubes. These lots were chromized at 2 different time-temperature levels (2135°F for 12 minutes and 1900°F for 120 minutes) with chromizing packs prepared using alumina of different grain sizes. Four different alumina grain sizes were included in the experiment. Half of the tubes were sandblasted prior to coating. The remaining tubes were coated without sandblasting. Evaluation of these tubes is in progress.

Use of the coarse grades of alumina resulted in a granular deposit on the surface which was identified by x-ray diffraction to be chromium. This deposit was quite tenacious but could be removed by the sandblast treatment. The most significant results to date are definite improvement in the level and uniformity of adherence over the length of tubes which had received the sandblast treatment, and a decrease in adherence with an increase in alumina mesh size.

(3) Effect of Chromized Substrate Composition on Ceramic Adherence

Microprobe and x-ray fluorescence work conducted in the previous report period on S8DS cup-plugs indicated a relationship between coatability and composition based on Cr/Ni ratios. Additional work was conducted on cup-plugs and on tubes.

Thirty-one cup-plugs were scanned for Cr and Ni with an x-ray fluorescence spectrometer and the Cr/Ni ratios were computed on the basis of the obtained intensities. The plugs were subsequently coated with SCB and examined. Ten were found to exhibit chipping, giving an overall yield of 68% acceptable.

These tests substantiated the values which were reported previously; i. e., cup-plugs with Cr/Ni ratios of about 1.5 were found to exhibit the best coatability.

Samples from 30 tubes which had been processed in the same manner as the cup-plugs were scanned for Cr and Ni with an x-ray fluorescence spectrometer and the Cr/Ni ratios were computed on the basis of the obtained intensities. The specimens were subsequently coated and tested for adherence. Eight of the specimens were found to exhibit an adherence index of 5 or less. A plot of the adherence data vs the Cr/Ni ratios, indicated that the degree of coatability peaked between the Cr/Ni ratio limits of 0.5 and 1.7. This relationship compares favorably with those found for the cup-plugs, thus substantiating the existence of a relationship between Cr/Ni ratio and coatability.

2. Closure Welding

Process improvement studies continued toward improvement of the S8DS closure weld process capability. A statistically designed experiment was conducted to evaluate effects of assembly and welding parameters on weld penetration. It was found that runout in the fit between the tube and cup-plug weld flange and variability in the backup gap between the tube wall and cup-plug barrel were the most sensitive parameters.

Based on these results, a group of twenty assemblies was processed using improved fit-up procedures. Each assembly was radiographed to verify cup-plug-to-tube fit. Destructive

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evaluation of these welds showed a 100% yield in exceeding the S8DS minimum weld penetration specification of 0.0067 inch. Results of this process capability test are summarized in Table 8.

TABLE 8
PROCESS CAPABILITY FOR CLOSURE
WELD PENETRATION

Number of assemblies welded	20
Number of metallographic views/weld	4
Total metallographic views	80
Average minimum weld penetration (in.)	0.0095
Standard deviation (in.)	0.0011
Process capability (in.) at 95% confidence level	0.0074

3. Fuel Element Evaluation Testing

The SNAP 8 fuel element testing program has been redirected within GFY 1966 budget and program guidance. Performance tests of early S8DS fuel elements have been terminated. Comparative tests of AI-8763D coated (S8ER) and SCB-1 coated (S8DS) elements have been terminated. Performance tests of S8ER elements have been completed except for evaluation in support of the S8ER core examination. The primary effort is in support of the S8ER core evaluation and the S8DS process improvement program. Cladding ductility tests of six S8ER fuel elements were completed. Testing of the first two groups of S8DS elements assembled from AI-chromized tubes was completed. Testing of a group of S8DS elements assembled with improved AI chromized tubes was initiated.

a. S8ER Evaluation Testing

A group of seven cladding assemblies from S8ER performance test fuel elements was selected for cladding burst tests. Three of the cladding assemblies had been aged for 10,000 hours at 1300°F and 4 assemblies were aged for

10,000 hours at 1400°F. At the end of the reporting period, six of the assemblies had completed burst testing. Initial evaluation of the data shows an average yield (0.2% offset) at a hoop stress of about 30,000 psi. Ultimate strength data are widely scattered and may be inconclusive in predicting the ultimate strength of other Hastelloy-N material. This is because most of the cladding ruptures are in the form of pinholes developing within 2 inches of either end of the assemblies. Two of the assemblies failed at the blind end cap weld. One of the welds failed with only 1000 psi internal pressure (hoop stress of about 27,000 psi). Resulting strain at rupture ranged from about 0.2 to 4.1%, corresponding to 27,000 to 41,000 psi stress. No correlation was seen with aging temperature.

During this report period, the cluster of 5 membranes (blind-end, AI-8763D ceramic) was removed from test after accumulating a total of about 26,000 hours at temperature. During this time, test temperatures were varied between 1200 and 1500°F, while internal hydrogen pressures were between 1 and 5 atm. Although there is a considerable variation in the permeation data, degradation of the hydrogen barrier appears to have been significant. For example, early testing at 1400°F and 3 atm showed a cluster permeation of 0.2 cc(STP)/hr with a surface area of $\sim 500 \text{ cm}^2$ at temperature. Final testing, also at 1400°F and 3 atm, showed a cluster permeation of 0.4 cc(STP)/hr, but with only $\sim 200 \text{ cm}^2$ of surface area at temperature.

After removal from the test furnaces, the cluster was separated, and two of the membranes were subjected to destructive analyses. Figure 5 shows the typical appearance of these two membranes after sectioning. The effect of the temperature gradient was clearly indicated by the color of the ceramic — dark green at the blind end, gradually changing to a light green at the pressure probe end. And of more significance, there are no areas of bare metal.

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Figure 5. An AI-8763D Ceramic Membrane after 26,000 Hours at Temperature

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Figure 6. Residue from AI-8763D Ceramic Membrane after 26,000 Hours at Temperature

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Figure 7. Residue from an S8ER Fuel Element (AI-8763D Ceramic) after More Than 10,000 Hours at 1400°F

After removing the pressure end cap, a quantity of residue was poured from the membrane shown in Figure 5. This residue is shown in Figure 6. For comparison, Figure 7 shows a typical quantity of residue removed from an early S8ER design fuel element (AI-8763D ceramic) which had been at 1400°F for more than 10,000 hours during performance testing. Figures 6 and 7 illustrate the difference in ceramic degradation between testing fuel elements and testing membranes.

Photomicrographs of cross sections from the membrane of Figure 5 show an absence of defects in the ceramic. In addition, there appears to be an excellent bond between the ceramic and the cladding tube. Typical photomicrographs are shown in Figure 8.

b. S8DS Evaluation Testing

(1) Early AI-Chromized Fuel Elements

Early in-house chromizing development work led to the assembly of two groups of fuel elements.

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1. MOUNTING MATERIAL
2. Al-8763D CERAMIC
3. HASTELLOY-N TUBE

a. PRESSURE PROBE END

b. BLIND END

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Figure 8. Typical Membrane Sections after 26,000 Hours at Temperature

The first group was assembled from cladding tubes which had been unsatisfactorily chromized by a vendor and which were later rechromized by in-house techniques. The second group of fuel elements, designated process development fuel elements, were assembled from tubes which were chromized only by in-house techniques. The fuel elements were permeation tested prior to and after low-level vibration and 25 ramp heat cycle inputs in order to evaluate the chromizing processes. The input levels for these tests are given in Table 9. Test results for these elements are summarized in Table 10. The variability in

performance of these early elements has since been eliminated through S8DS process improvement developments.

Seven of the fuel elements listed in Table 10 were tested in the permeation scanner to determine the location of the hydrogen losses on each fuel element. All but two of the fuel elements show the greatest hydrogen loss from the closure end (72% average). Elements N-2981 and N-3950 show the greatest loss from the blind end (61% average). Table 11 lists the data from the scan tests on these 7 fuel elements.

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TABLE 9
VIBRATION AND RAMP HEAT LEVELS

	Magnitude	Frequency (cps)
Vibration *	3/16 in. double amplitude	5 to 13
	3.4 g	13 to 400
	5 g	400 to 2000
Ramp Heat	Heat at 300°F/min from ≤400°F to 1400°F; Maximum cooling [†] from 1400°F to ≤400°F. (The above describes one complete cycle.)	

*Vibration inputs are the same for each of three mutually perpendicular axes, with a constant octave sweep rate requiring 5 minutes for each axis.

†Maximum cooling is the rate at which the fuel element cools naturally when the power is shut off at 1400°F. Peak rate obtainable is about 300°F/min for a short period.

(2) Improved AI-Chromized Fuel Elements

Seven developmental S8DS fuel elements were assembled using tubes chromized by AI at 2135°F for 12 minutes. The cladding tubes were prepared for coating by sandblasting with a newly developed 360° nozzle. These fuel elements, which are the end product of the process improvements described earlier in this report, were subjected to the test inputs of Table 9. The test results are summarized in Table 12. A comparison of these results (Table 12) with the data in Table 10 shows the performance improvement achieved over the earlier AI-chromized fuel elements.

Based on the initial testing results, these seven fuel elements exhibit very stable and consistent performance. Additional evaluation tests of these fuel elements have been initiated. These tests include thermal endurance, ramp heat, and thermal cycle sequences.

4. Irradiation Tests

a. Low-Temperature Fuel Materials Irradiation, NAA-116 Series

The objective of the low-temperature fuel materials irradiation program is to provide irradiated fuel samples for use in the correlation of post-irradiation annealing studies with high-temperature inpile performance of the fuel. The purpose of the annealing tests is to study the swelling behavior of the fuel as a function of annealing temperature and time, and as a function of the metallurgical parameters of the materials. These data are also expected to yield information on the breakaway swelling behavior of the fuel.

As previously reported, the NAA-116-1 and -2 capsules were irradiated in a Hanford reactor to nominal burnups of approximately 0.15 and 0.7 met. at. %, respectively. Much of the work on the hot-cell examination of the capsules was completed in FY 1965 and has been reported in the last four quarterly progress reports. In summary, the results indicated that unexpected volume changes occurred in the fuel during the irradiations which were performed at fuel temperatures below 625°F. The normalized volume changes indicated 5 to 9% increase in volume per metal atom percent burnup (3.7×10^{20} fissions/cm³). Subsequently, it was found that by thermally cycling unirradiated fuel samples over the temperature range of 120 to 1090°F, an increase of 10 to 12% in the volume of the samples resulted after 500 cycles. This behavior has been tentatively attributed to ratcheting of the precipitated metallic uranium particles in the hydride matrix.

During this report period, the unirradiated fuel samples from the thermal cycling tests were annealed (211 hours at 1300°F) under the

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TABLE 10
DATA OF 31 S8DS CHROMIZING DEVELOPMENT FUEL ELEMENTS

	Element Number	Hydrogen Permeation at 1400° F [cc(STP)/hr]					
		Pre-Vibration		Post-Vibration		Post-25 Ramp Heats	
		1	2	1	2	1	2
Rechromized	N-2981	0.54	0.53	0.58	0.63	2.2	2.5
	N-3422	0.69	0.62	0.71	0.65	9.1	8.1
	N-3432	0.93	0.97	0.97	0.96	1.6	1.3
	N-3438	0.82	1.0	1.0	0.84	1.0	0.96
	N-3439	0.44	0.47	1.4	1.3	1.2	1.1
	N-3444	0.89	0.93	1.0	1.0	1.0	1.0
	N-3476	0.57	0.73	0.73	0.68	0.84	0.95
	N-3477	0.32	0.33	0.37	0.40	0.41	0.80
	N-3483	0.57	0.55	0.69	0.69	7.3	5.3
	N-3487	0.87	0.84	1.5	1.3	8.7	5.2
	Average	0.66	0.70	0.90	0.84	3.3	2.7
Process Development	N-3967	0.66	0.65	0.87	0.85	1.4	2.8
	N-3968	0.50	0.48	0.71	0.81	0.77	0.65
	N-3969	0.69	0.73	0.88	0.77	6.3	7.3
	N-3970	0.34	0.40	0.47	0.40	3.6	4.5
	N-3973	0.47	0.56	0.65	0.50	5.0	6.2
	N-3992	0.41	0.39	0.57	0.62	6.3	5.2
	N-3993	0.20	0.26	0.27	0.25	7.3	6.8
	N-3996	0.68	0.67	0.89	1.1	2.4	2.0
	N-4002	0.34	0.33	0.40	0.45	0.85	1.1
	N-4003	0.22	0.29	0.24	0.11	0.63	0.65
	N-4011	0.26	0.25	0.45	0.50	4.1	5.3
	N-4014	0.26	0.28	0.58	0.43	5.9	7.0
	N-4025	0.61	0.65	0.97	1.0	0.93	5.0
	N-4026	0.39	0.50	1.0	0.95	5.1	7.4
	N-4032	0.27	0.32	0.64	0.60	0.65	0.52
	N-4034	0.41	0.35	0.51	0.60	0.96	0.47
	N-4035	0.53	0.63	1.35	0.98	11.3	12.4
	N-4036	0.44	0.50	0.84	0.66	0.79	0.73
	N-4037	0.30	0.35	0.40	0.51	5.1	10.1
	N-4038	0.35	0.33	0.44	0.37	0.59	0.43
	N-4042	0.44	0.47	0.92	0.83	4.1	3.0
	Average	0.42	0.45	0.67	0.63	3.5	4.3

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TABLE 11
PERMEATION SCANNER TEST RESULTS

Element Number	Hydrogen Permeation at 1400°F [cc(STP)/hr]		Flow (%)		
	Pre-Scan	Total Scan	Closure 2-1/4 in.	Middle 12-5/8 in.	Blind 2-1/4 in.
N-2981	2.2	1.6	21	10	69
N-3487	8.7	8.0	78	12	10
N-3948	0.45	4.5	83	6	11
N-3950	1.2	1.0	29	18	53
N-3952	0.62	0.69	42	23	35
N-3958	11.5	11.5	83	—	—
N-4026	5.1	5.9	74	6	20

TABLE 12
DATA OF 7 S8DS DEVELOPMENTAL
FUEL ELEMENTS

Element Number	Hydrogen Permeation at 1400°F [cc(STP)/hr]			
	Acceptance	After Vibration	After 5 Ramp Heats	After 25 Ramp Heats
4122	0.44	0.43	0.35	0.42
4131	0.36	0.30	0.32	0.30
4257	0.27	0.42	0.46	0.52
4261	0.33	0.36	0.47	0.31
4285	0.28	0.34	0.34	0.37
4302	0.32	0.37	0.34	0.51
4308	0.39	0.36	0.36	0.46
Average	0.33	0.37	0.38	0.41

same conditions as for the irradiated fuel. The results are presented in Table 13 with the values obtained from the irradiated fuel for comparison purposes.

The important observation is the density recovery of the thermally cycled fuel, which is similar to that for the irradiated fuel. Since the density of both irradiated and unirradiated samples was significantly recovered after annealing, and

the cycled fuel was treated to promote alpha uranium ratcheting, a strong indication exists that uranium ratcheting was responsible for the swelling of the NAA-116 fuel samples during irradiation.

The cycling test is being repeated with both fueled and unfueled specimens in order to verify that the ratcheting of the precipitated metallic uranium particles is responsible for the

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TABLE 13
RESULTS OF ANNEALING TREATMENTS OF THERMALLY
CYCLED AND IRRADIATED FUEL SAMPLES

Thermally Cycled Unirradiated Fuel	Sample Number	Density ³ (gms/cm ³)			
		Pre- Cycled	Post- Cycled	Annealed	
	624D3-I	6.291	5.548	6.114	
	624D3-II	6.064	5.424	6.035	
	628B2-III	5.846	5.218	5.860	
Irradiated Fuel		Pre- Irradiated	Post- Irradiated	Annealed	
		14	6.282	6.209	6.259
		19	6.554	6.451	6.520
		20	6.188	6.091	6.176
		22	6.566	6.400	6.483

unexpected growth of the fuel samples. In addition, density changes as a function of the number of cycles will also be determined.

With respect to the irradiated samples, dosimeter calculations were concluded for the NAA-116-2 capsule and a value of 0.69 met. at. % burnup was obtained. This concludes the hot-cell studies of the capsules with the exception of a re-run of the isotopic burnup analysis of NAA-116-2 material and possibly an effort to study the uranium precipitates by an electron fractograph technique. The burnup analysis is being repeated because it appears that the initially obtained value is excessively high.

b. Engineering Irradiation

(1) NAA-115-1 Fuel Element Engineering Irradiation

The NAA-115-1 irradiation assembly consists of six separately controlled experiments and contains a total of twelve sublength S8ER fuel elements. Experiments 1 and 2 contain four elements each and experiments 3, 4, 5, and 6 contain one element each. These experiments, currently being irradiated at Hanford, are

designed to achieve the equivalent burnup of the SNAP 8 core operating at 600 kw for 10,000 hours. The results of these experiments will augment the evaluation of the S8ER core performance and will provide detailed information regarding fuel element performance capability.

Ninety percent of the design burnup has been obtained, and experiments 1, 2, 5, and 6 have operated at design temperatures for 83% of the available full-power reactor operation time. As previously reported, experiments 3 and 4 are operating in the helium mode at estimated peak fuel temperatures of 1150 and 1100°F, respectively.

Major efforts during the reporting period were devoted to making the necessary preparations for discharge of the assembly from the reactor and shipment to the AIHL. To ship the assembly, it is necessary to sever it in several places. A guillotine, which performs this operation without damage to the assembly, was designed, built, and successfully tested. The procedures for the discharge and cut-off operations were prepared and reviewed. A twenty-four-point strip-chart recorder was serviced,

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calibrated, and sent to the reactor site where it will be utilized to monitor various temperatures within the assembly from the time that the regular instrumentation lines are severed until the assembly is discharged. The flux depressors, or shroud tubes, which surround each experiment, will be removed at the reactor site and buried at Hanford. Procedures for this operation have been developed. The transfer cask which will be used to ship the experiments to AI has arrived at Hanford and is ready for use. In summary, all preparations for the discharge have been completed.

(2) NAA-115-2 Fuel Element Engineering Irradiation

The NAA-115-2 irradiation test plan encompasses the same parameters as the NAA-115-1 except that the NAA-115-2 irradiation assembly contains S8DS sublength fuel elements and it will be irradiated to the equivalent of two years of S8DS operations.

Irradiation continued at Hanford and all operating data indicate that the experiment is functioning as designed. Design temperatures have been achieved during 79% of the available full reactor operation time.

In addition to continued irradiation, the major effort during this reporting period consisted of data reduction and analysis. Of considerable significance is the performance of the two Geminol thermocouples placed within one of the fuel specimens. These thermocouples continued to operate in the hydrogen reducing atmosphere with no degradation. The chromel-alumel thermocouples placed in similar positions in the NAA-115-1 assembly showed degradation after only three days. Another significant achievement is the use of dynamic flux monitors to provide continuous indication of the relative thermal neutron flux. Three of these monitors are operating in the NAA-115-2 assembly and they have provided valuable information during

reactor startup and experiment operation. Of special value is their ability to indicate relative flux changes during the reactor cycle, thus assuring the personnel operating the experiment that temperature changes occurring within the experiment are the result of external conditions.

(3) NAA-117-1 Fuel Element Engineering Irradiation

The NAA-117-1 irradiation test plan is designed to evaluate the effect of increased power density on fuel element performance over a range of temperature and fuel compositional parameters. The sixteen sublength fuel elements will be irradiated to a burnup equivalent to two years of SNAP 8 reference design operations at 1.2 Mwt.

Irradiation at Hanford continued during the reporting period and operating data indicate that the experiments are functioning as designed. Design temperatures have been achieved during 67% of the available full-power reactor operation time. The chromel-alumel thermocouples placed within a fuel specimen in one of the experiments have degraded in a manner similar to that of the one in NAA-115-1. All other thermocouples are functioning properly.

(4) NAA-121-1 Prototype Fuel Element Irradiation

These experiments will evaluate the performance of prototype full-scale fuel elements at 600-kwt SNAP reactor conditions of temperature, burnup, and burnup rate. Irradiation will be performed at Hanford. The description of the experiments has been discussed in detail in previous quarterly reports.

During this reporting period, fabrication of component parts continued and Figure 9 shows those which have been completed. The heat transfer and stress analyses and design of the experiments are complete. Refinements have been made in the analytical model for the design of the flux depressors. It has been shown that

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Figure 9. NAA-121 Components

the use of existing physics data in the nuclear analysis generates uncertainties in the thermal neutron flux produced within the shaped flux depressor. The magnitudes of these uncertainties are 9% in the region of the highest thermal neutron flux and 42% in the region of the lowest flux. Design of a physics test was completed for irradiation in the Hanford Snout Facility. This experiment will provide information regarding the cadmium ratio within the depressor. This infor-

mation will improve the reliability of the nuclear analysis and allow more accurate design of the flux depressor.

(5) S8ER Core Examination

The screening examination of the S8ER core was completed and the detailed examination of selected fuel elements was started at AIHL. Results of the examination are included in Section VI-D of this report.

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V. COMPONENT DEVELOPMENT

The component development effort is concentrated on the evaluation testing of the S8DS design components at S8DS operational conditions. This evaluation testing includes performance mapping at the operational temperature and vacuum environment, effects of multiple thermal cycles at the maximum operational rate, effects of combined operational thermal-vacuum-irradiation environment, and long-term performance at operational temperature and vacuum.

Two each of the control drive actuators, position sensors, and limit switches have completed 1000 hours of operation under combined thermal-vacuum-irradiation environment with no measured loss of performance. Two control-drum actuators have completed approximately 5,000 hours of thermal-vacuum endurance.

Another actuator has completed 80 startup and thermal cycles. The first developmental control-drum drive and scram mechanism test assembly which includes the drive components such as the gear, actuator, and bearings has completed 4,200 hours of endurance testing. During this test period, 320 drive-in and scram cycles and 13 thermal cycles were completed.

Additional evaluation tests on the position sensor, control-drum bearing, and limit switch have been initiated. The design of both the temperature sensor and the temperature switch has been modified to facilitate fabrication and improve performance. The developmental test components are now being fabricated.

A. SCRAM MECHANISM

Safe operation of the SNAP 8 reactor system during ground testing requires means for quickly shutting down the reactor by withdrawal of the control drums. A control-drum scram drive

mechanism has been designed which is capable of operating under the S8DS environmental requirements. Details of design and operation of the system were reported in a previous progress report.*

Two developmental scram drive assemblies are being subjected to continuous long-term test in an S8DS environment. The test chamber pressure is 1×10^{-5} torr and the scram clutch operating temperature is 850°F.

One unit (S/N-001) has been operating in this environment for 4,210 hours. During this time the unit has performed 320 scram cycles. A scram cycle consists of:

- 1) Stepping a simulated drum mass to its full-in position,
- 2) Releasing the scram clutch mechanism by interrupting the clutch power (simulated scram signal),
- 3) Outward rotation of the drum mass under scram spring power (109° rotation to snubber shaft),
- 4) Deceleration of the drum mass against the spring loaded snubber shaft (26° additional rotation),
- 5) Rewinding the sram spring (135° maximum) by stepping the actuator, and
- 6) Latching the fully wound scram spring torque by energizing the scram clutch.

Thirteen thermal cycles have been performed on this unit. The thermal cycles consists of cooling the assembly to room temperature following a drum scram, a 36-hour dwell period at room temperature, then raising the temperature to the operating level. The cooling rate

*C. R. Johnson, "SNAP 8 Quarterly Progress Report, May-July 1964," NAA-SR-9992 (SRD), September 22, 1964

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averages 10°F/min for the initial 150°F of temperature reduction followed by a progressively slower rate. The heat-up rate averages 10°F/min from room ambient to operational level.

After 3400 hours of testing, the component operating temperatures were increased approximately 75°F to reflect a revision in the SNAP 8 thermal analysis. The current operating temperatures of various parts of the experimental drum-drive assembly are:

Clutch temperature	850°F
Gear bearing temperature	1000°F
Control-drum actuator	1010°F

After 275 scrams and 3820 hours of environmental test, the plunger release pawl failed to withdraw to its fully retracted position. Due to this condition, the succeeding drum scram resulted in an impact between the pawl and the pawl release arm. Examination revealed that the failure of the pawl to retract was due to a minor tolerance error. This error had been corrected on the S8DS system components. The pawl parts were reworked to the S8DS configuration. No further operational difficulties have been encountered with the snubber assembly.

During the rework of the snubber assembly, the amount of wear on the plunger ratchet teeth was measured. The maximum wear on any tooth was less than 0.002 in. The ratchet teeth as well as the pawl are coated with a cobalt-based alloy containing chromium and tungsten. Both the pawl and the plunger wear surfaces are coated with MoS₂ dry-film lubricant.

A second scram drive assembly (S/N-002) has been operating, in the environment described above, for 1050 hours which includes 50 scram cycles and 11 thermal cycles.

This test was interrupted when the actuator failed to step due to a malfunction of its brake mechanism. It was concluded that the cause of failure

was the same as for the 3rd dwell test unit, reported in the following section (V-B). The actuator was reworked to the S8DS system configuration and the performance test on the scram drive assembly was resumed.

During each scram cycle, the elapsed time for rotating the drum 23° and 109° is recorded. These measurements are made by recording limit switch actuations at the 23° and 109° drum positions on a multichannel oscillograph recorder. The initiation of the drum scram is indicated on the recorder paper by the interruption of the clutch voltage. Figure 10 is a composite example of the multichannel oscillograph traces showing typical events as a function of elapsed time.

The scram time for each scram kit assembly is affected by friction torque, spring rate, and scram spring starting torque. The test data indicate, however, that the scram times for a particular kit are repeatable. Scram time data from experimental scram kits S/N-001 and -002 are summarized in Table 14.

B. CONTROL-DRUM ACTUATORS

The SNAP 8 reactor is controlled by rotating the external beryllium control drums to increase or decrease the fraction of leakage neutrons. The control-drum drive is mechanically connected to an electromagnetic actuator which rotates and positions the reflector drums in 0.26° steps through a gear train upon command from a controller. The actuator incorporates a built-in mechanical brake which locks the control drum during the nonoperational period. The release of the brake and actuator operation are sequenced to prevent free wheeling of the control drum.

The S8DS actuator is a direct-current, variable reluctance stepping motor. The motor is energized with d-c voltages in discrete pulses which cause the rotor to turn in steps of 1.8°.

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Figure 10. Scram Clutch Characteristics, Engagement and Release Time

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TABLE 14
RECORDED SCRAM TIME DATA

Scram Kit Number	*Average Elapsed Time for 23° Drum Motion (millisec)	Maximum Deviation From Average Time (millisec)	*Average Elapsed Time for 109° Drum Motion (millisec)	Maximum Deviation From Average Time (millisec)
S/N-001 (From 320 scrams)	180	+19 -14	494	+48 -13
S/N-002 (From 50 scrams)	225	+25 -11	553	-15 -24

*Design requirement for scram time: 500 millisec for 23° and 2 sec for 109°.

The rotation may be in either direction as required. The controller is designed to produce two actuator steps of 1.8° or a total of 3.6° for each operation. The geared drive reduces the 3.6° actuator output to 0.26° of control-drum rotation.

1. Bench Test and Assembly

Fifteen developmental and fourteen S8DS actuators have been assembled. With the ex-

ception of one grounded brake and minor mechanical difficulties, there have been no outstanding problems in the manufacture of these units. The performance data of all fifteen developmental units and seven S8DS units tested to date have exhibited torque and output characteristics in close agreement. The average performance test curve of ten developmental units is shown in Figure 11.

The S8DS actuator, which developed a ground in the brake solenoid prior to acceptance test, is being repaired. The ground, caused by the close proximity of a coil lead with the brake housing, was cleared by the relocation of the coil leads after removal of encapsulant. The use of flexible coil leads in the S8DS coil design has permitted the repair of the solenoid assembly without a complete rework. The solenoid with leads exposed after removal of the encapsulant, is shown in Figure 12.

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Figure 11. Dynamic Torque vs Field Current, S8DS Design Control-Drum Actuator

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Figure 12. Brake Solenoid Assembly After Removal of Lead Encapsulant

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Figure 13. S8DS Actuator Mounted on Vacuum-Temperature Test Fixture

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Figure 14. S8DS Experimental Control-Drum Actuator Brake Response

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2. High Temperature and Vacuum Tests

Several actuators are presently in various stages of long-term endurance and evaluation tests. Two units have approached the 5000-hour milestone. The successful performance of these two actuators has demonstrated that the S8DS actuator can perform in accordance with specification requirements for extended periods of time. A typical high temperature and vacuum test stand with an actuator in position is shown in Figure 13. The actuator drives a calibrated load on a torque arm. The angular displacement of the torque arm can be converted to actuator output torque. The output torque as a function of stator current is measured during the test. The minimum current necessary to release or "pull in" the brake is also measured as a means of monitoring the brake spring and release force. Oscillograms as shown in Figure 14 are taken to verify acceptable brake performance as well as to determine the speed of brake response.

a. Performance (Dynamic Stepping)

Each actuator is performance checked at 1025°F and high vacuum. This temperature and vacuum test serves to demonstrate ability of an actuator to perform without malfunction in the S8DS environment. A list of the test data accumulated on experimental actuators is shown in Table 15. The repeatable data and test results indicate that there has not been a significant change in output or performance on any developmental test unit due to, or as a result of, exposure to the high temperature and vacuum environment. It also shows the uniformity in performance between actuators. A performance output curve for actuator S/N-006 before and after exposure to temperature and vacuum, as shown in Figure 11, indicates no significant change in performance for current values as high as 150% of the normal 28-volt current input at 1025°F.

b. Nonoperation or Dwell

In order to investigate the effect of long-term dwell, three actuators were subjected to long-term periods of nonoperation in the high temperature and vacuum environment. After 2100 hours at dwell, each of the three actuators was performance checked for brake release and stepping ability. Two actuators matched their original minimum current required for brake release and stepping. The brake of the third actuator did not release when the normal 28-volt dc was applied to the brake coil; however, the actuator functioned and stepped as required when subjected to the standard operational procedure in which the 28-volt dc is applied to the brake and phase coils simultaneously. Subsequently, the brake operated normally with the pre-test minimum brake coil. A tabulation of the test data is shown in Table 16.

Examination of the toothed brake area of the third unit did not reveal any positive indications of self welding. As shown on Figure 15, the sharp edges and burrs had not been removed during fabrication or prior to assembly. The sticking of the brake surfaces was attributed to the high unit pressure at these protrusions, contributing to mechanical interlocking.

The corresponding surfaces on S8DS system actuators were examined and found to have been deburred and free of all sharp edges and protrusions. This fact, and the use of an effective molybdenum disulfide anti-adhesion coating on these surfaces (which had not been used on the initial developmental actuators), should prevent the occurrence of this type of malfunction on the S8DS actuators. To verify that the proper dressing of toothed components and the use of an effective anti-adhesion coating can prevent brake tooth "adhesion" in the space vacuum, the affected sections of the third actuator were modified in accordance with S8DS system procedure and replaced on test. Eighteen hundred hours of additional dwell test have been completed.

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TABLE 15
S8DS DEVELOPMENTAL CONTROL-DRUM ACTUATOR PERFORMANCE

S8DS Developmental Control Drum Actuator			Brake Operation Current to "Pull In" (amp)		Dynamic Load Operation		
Serial Number	Application or use	Time at 1025°F (hr)	Initial at 1025°F	Last Reading at 1025°F	Load Stepped (in.-oz.)	Minimum Current to Step Load (amp)	
						Initial at 1025°F	Last Reading at 1025°F
001	BMI out-of-pile correlation	4890*	0.55	0.55	40	1.15	1.0
002	BMI out-of-pile correlation	4635*	0.6	0.62	40	1.18	0.98
003	BMI inpile test	1191* (1100 hr inpile)	0.56	0.58	40	1.03	1.0
004	BMI inpile test	1230* (1100 hr inpile)	0.54	0.58	40	1.08	1.08
005	Scram kit test No. 1	4210	0.6	-	40	1.1	-
006	Endurance Evaluation "Oil Contam"	2829*	0.5	0.57	120	1.7	1.67
007	Shock and vi- bration evaluation	56	0.5	0.5	40	0.88	0.95
008	Scram kit test No. 2	1230*	0.65	0.64	84	1.23	1.28
009	Scram kit accept- ance test unit	29	0.55	0.55	40	1.0	1.05
010	Startup and ther- mal cycle	100* and 83 cycles	0.55	0.52	84	1.3	1.25
011	Startup and ther- mal cycle	500* and 31 cycles	0.55	0.54	40	0.95	0.95
012	Scram kit test No. 3	124	0.65	0.62	40	0.90	0.85
013	Hold for spare (EMI test)	96	0.48	0.47	40	0.9	0.85
014	Hold for spare (EMI test)	300	0.6	0.6	40	0.88	0.9
015	BMI out-of-pile UHV correlation	540*	0.5	0.52	40	0.95	0.9

Design requirement: Torque - 40 in.-oz minimum
Input at 1025°F with 28 v
Phase current: 1.6 amp maximum for 40 in.-oz torque
Brake current: 0.9 amp maximum

*Test continuing

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TABLE 16
EFFECT OF LONG-TERM DWELL AT 1025°F IN VACUUM ON S8DS
DEVELOPMENTAL CONTROL-DRUM ACTUATORS

Serial Number	Time at 1025°F (hr)		Brake Operation Minimum Current to Pull in or Release Brake (amp)			Dynamic Load Operation			
						Load Stepped (in.-oz.)	Minimum Current to Step Load (amp)		
	Total Accumulated (End of dwell)	In "Dwell" (Non-operating)	Room Ambient Bench Check	Initial at 1025°F	After Dwell at 1025°F		Room Ambient Bench Check	Initial at 1025°F	After Dwell at 1025°F
001	3790	2190	0.61	0.55	0.52	40	0.9	1.15	0.9
002	2835	2183	0.62	0.60	0.62	40	1.03	1.18	0.98
006	2829	2179	0.5	0.5	0.57	120	1.7	1.7	1.67

c. Coil and Insulation Resistance

After the initial startup procedures, coil and insulation resistance test data are taken on a daily or weekly basis in addition to the performance checkout. There have been no changes in coil or phase resistance due to the long-term exposure to the 1025°F environment. The use of chromium-clad copper conductors in the S8DS actuator coils has provided a relatively stable wiring system as evidenced by the 5000-hour test results.

As reported previously,* insulation resistance-to-ground has leveled off after 200 to 300 hours at the S8DS environment. An extension of the typical insulation resistance data is shown in Figure 16. The initial test data for S/N-015, which is undergoing a thermal and vacuum endurance test in an ion-pumped system, has been added to the curve sheet. The test data shows that the initial steep degradation of insulation resistance typical of the other units in diffusion pumped systems does not occur in an ion-pumped vacuum system which is not subject to "oil backstreaming". The flat insulation characteristic is typical of an ion-pumped system in which there are no pumping contaminants

that can degrade the insulation system of the component on test. The spread of insulation resistance shown is attributable to the assembly and initial contamination as well as to the wiring and lead arrangement in the stator wherein the leads of one phase are physically closer to ground than in another phase.*

3. Consecutive Startup and Thermal Cycle Test

The startup cycle is the most severe condition under which an actuator must perform. The actuator must step with 28 volts applied continuously for 1863° of shaft rotation (135° of drum rotation). The extremely high current density in the wire as well as the rapid internal temperature increase is conducive to the formation of internal hot spots and wire burnouts. After the startup stepping cycle, the actuator windings are subjected to both internally and externally induced temperature rises due to nuclear irradiation and heat transfer from the reactor. The conditions of the test and details of operational procedures were described previously.* The two actuators undergoing this test have completed 83 and 31 startup and thermal cycles, respectively, with no significant change in output performance or torque.

*D. G. Mason, "SNAP 8 Progress Report, May-July 1965", NAA-SR-11492 (CRD), September 30, 1965

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INTERNAL TEETH

EXTERNAL TEETH

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Figure 15. Tooth Surfaces of Sticky Actuator Brake

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Figure 16. Phase Insulation Resistance-to-Ground vs Time for S8DS Design Control-Drum Actuator

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Figure 17. S8DS Design Control-Drum Actuator Performance and Coil Resistance at 1025°F vs Number of Startup and Thermal Cycles

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The performance data for the two actuators undergoing this test, Figure 17, verify that the actuators can withstand repeated thermal and startup cycling with no significant change in resistance or performance values.

C. BEARINGS

The SNAP 8 drum bearings are being tested as representative bearings for all other bearings of the reactor. These bearings are designed to meet ground test (S8DS) requirements and space environment requirements. The bearing details are shown in Figure 18. The shafts, thrust faces, and sockets are alumina-coated Inconel-X. The balls are alumina-coated Inconel-X with carbon-graphite bushings. Environmental requirements include: temperatures up to 1150°F, 10^{-5} torr vacuum (S8DS), typical launch and space environment, and high-flux radiation. The drum bearings have a maximum allowable torque of 3.5 in.-lb. Tests are being conducted to determine performance of bearings when subjected to the various required environments.

One S8DS drum bearing set has started testing at 10^{-5} torr. Maximum torque at 1150°F is 1.2 in.-lb after 680 hours with an 8.45-lb radial load and 26-lb axial load. Torque varies as a function of temperature as shown in Figure 19. Decreasing friction as temperature increases to approximately 600°F is a typical characteristic for a carbon-graphite to Al_2O_3 sliding couple. A test using variable thrust loads and a constant radial load was run at 70°F and again at 1150°F. These tests indicate the frictional running torque increases in a linear manner with increased loads as shown in Figure 20. Calculations show the approximate coefficient of friction at room temperature is 0.3 and at 1150°F is 0.05. The bearings were examined after 680 hours at 1150°F and found to be in good condition. The S8DS bearing Test No. 1 set-up is shown in Figure 21. A schematic of

the bearing arrangement and loading is shown in Figure 22.

A summary of all SNAP 8 drum bearing performance tests is shown in Table 17. A total of 18,180 test hours has been accumulated at 1150°F in vacuum.

D. DRUM POSITION-SENSING SYSTEM

The drum position-sensing system measures the reactor control-drum angular position and provides an output signal for diagnostic purposes. The desired system accuracy is $\pm 1\%$ of full scale. Since the sensor is mounted on the reflector assembly, it must be capable of operating in the reactor environment throughout the 10,000-hour life of the nuclear system.

1. Transmitter

A rotary variable-reluctance (differential transformer) type of sensor was developed for this application. The stator contains one primary and two secondary windings. The magnetic rotor is shaped so that the coupling to one secondary winding, and hence its output voltage, is at a maximum when the output voltage from the other secondary winding is at a minimum. The demodulator is designed in such a manner that the output voltages are added in series-bucking, changing polarity at the center of the range of rotation.

Fabrication of 10 development units was completed. Two units (S/N-006 and S/N-008) are under test in a high temperature-vacuum-radiation environment (see Section V-G). S/N-001 and S/N-002 are in test as part of the scram drive assemblies (see Section V-A). S/N-003 and S/N-004 are being thermal-vacuum acceptance-tested prior to a 10,000-hour endurance test. S/N-005 and S/N-007 will undergo 200 thermal cycles in vacuum. Test plans have not been formulated for the remaining two units.

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Figure 18. S8DS Control-Drum Bearing

Figure 19. S8DS Drum Bearing Friction vs Temperature

Figure 20. S8DS Control-Drum Bearing Friction vs Load

Figure 21. Controlled 10^{-5} Torr Vacuum Drum Bearing Test System

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Figure 22. Bearing Loading Fixture

TABLE 17
SNAP 8 CONTROL-DRUM BEARING TESTS

Test Number	Pressure (Torr)	Temperature (°F)	Duration at Temperature (hr)	Actuation Cycles	Maximum Torque at Temperature (in. -lb)
86	10 ⁻⁹	1150	4500	388	0.75
84	10 ⁻⁵	1150	4660	296	1.25
88*	10 ⁻⁵	1150	2230	291	1.60
S8DS #1	10 ⁻⁵	1150	680	455	1.2
87	10 ⁻⁵	1150	1060	225	2.0
85**	10 ⁻⁵	1150	5050	370	1.5
6 Sets			18,180	2025	

*Balls were solid carbon-graphite
**No dry film lube on balls

Figure 23 shows the thermal-vacuum test equipment used for the 10,000-hour endurance test. Seen on top of the bell jar is the sensor shaft positioning device. Performance data on S/N-003 has been taken in this chamber at various temperatures from 70 to 800°F. Curves plotted of the secondary series bucking output vs shaft angle reveal a temperature dependency similar to that described in the previous progress report for other units. This change in output can be directly related to changes in mutual inductances with temperature which

occur between the primary and both secondaries. The magnitude of the change is different for each secondary and varies with angle. The result is an output error which varies from approximately 2 to 8 degrees. The repeatable part of this error can be compensated by calibration.

The temperature effect is not detrimental to overall performance of S8DS precision position-sensing system, since the step-counting and verification logic senses a change of output from the demodulator when a step has occurred,

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Figure 23. Position Sensor Thermal-Vacuum Test Assembly

rather than a signal proportional to shaft position.

2. Position Sensor Demodulator

Five developmental demodulators were fabricated for design evaluation testing. One unit was placed on a long-term stability and endurance test at 120°F. During 500 hours of operation at this temperature, the demodulator remained stable within ± 5 mv ($\pm 0.1\%$) of full scale. Temperature cycling from 50 to 120°F at the completion of the run indicated a temperature coefficient of approximately minus 0.035%/°F. Repeatability over several temperature cycles was within ± 5 mv.

E. LIMIT SWITCH

During the acceptance test of the S8DS system switches, the high contact resistance reported in the previous progress report caused switches to be rejected. It was concluded that the high resistance was caused by an oxide film on the

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Figure 24. Limit Switch Dynamic Test Fixture

receptacle contacts. Elimination of the contamination by plating the contacts, abrasive cleaning, and vacuum bake-out was investigated. It was found that the contact resistance could be reduced by any of these procedures. Since several of the switches were already assembled and their terminations welded, the bake-out procedure, which could be performed on the assembled units, was adopted. The contact resistance decreased typically from 200 ohms to less than 2 ohms after bake-out.

Developmental testing continued with the successful operation of two S8DS-type switches in the HF-10 irradiation experiment. These two switches are continuing to operate satisfactorily in the radiation environment at 900°F after 1100 hours.

A developmental test fixture was designed and built which will allow switches to be tested dynamically under simulated S8DS conditions (see Figure 24). This fixture utilizes a cam to actuate the switches which are mounted within a heater in a vacuum system. The cam is operated by means of a rotary feedthrough from a motor external to the vacuum system. Testing was initiated on four switches and 70 thermal

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cycles to 1000°F and 100 switch actuation cycles have been completed. This test is scheduled for 10,000 hours at design conditions. The test will include 1000 actuations and 500 thermal cycles.

The static test which has been reported previously, wherein four developmental switches were being subjected to 1000°F thermal soak, was terminated. At some time between calibrations at 5000 and 6000 hours, a test fixture heater control failure caused the switches to be overheated. At the 6000-hour calibration, the switch point variation exceeded the specified 0.002 in. maximum. The loss of repeatability was due to excessive relaxation of the plunger spring. At the 5000-hour calibration, the switches had shown no measurable switch point or switching force change from the pre-test values.

F. TEMPERATURE DETECTOR AND SWITCH

1. Temperature Detector

The temperature detector provides voltage signals to the temperature switch which are proportional to the reactor outlet coolant temperature. The detector, in conjunction with the switch, establishes the limits of the reactor deadband and commands the controller to drive the drums whenever the outlet coolant temperature passes outside this deadband.

The S8DS design uses a platinum resistance temperature detector (RTD) which forms one leg of a three-wire Siemens bridge. As the resistance of the detector changes with temperature, the output of the bridge to the control winding of a high-gain magnetic amplifier in the switch varies accordingly. The bridge is adjusted to null at that detector resistance corresponding to the temperature at the middle of the deadband.

Drift testing at 1300°F of evaluation RTD's continued. These detectors are continuously

maintained at 1300°F to simulate long-term operating conditions. They are checked for drift every 500 hours by calibration in a triple point of water cell (0.01°C) utilizing precision laboratory resistance measuring techniques. Accuracy of this calibration converted to equivalent temperature at 1300°F is $\pm 0.2^\circ\text{F}$. Four detectors of an original 25 remain within the acceptable limits of -4°F shift in 10,000 hours. The RTD No. 5, which had shown considerable drift at the 8,000-hour calibration, failed during the next 500 hours and was removed from the test. Their drift in terms of equivalent set point shift is shown in Figure 25. All data is referenced to zero after a 1000-hour stabilizing period. This stabilization will be performed by the manufacturer on future units prior to acceptance.

High-temperature drift testing of three prototype S8DS detectors was continued at 1335°F in air. One detector, S/N-002, has accumulated nearly 1000 hours of drift testing in addition to the 1000-hour stability test. The 500-hour calibration indicated the detector resistance had drifted 0.029 ohms or -0.58°F related to the

Figure 25. Resistance Temperature Detector Drift Characteristics at 1300°F in Air Environment

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set-point. One detector, S/N-001, failed during the first 500 hours of the 1000-hour stabilizing period. The failure was found to be an open circuit at the junction between the element wire and the platinum lead wire. The cause of this failure has not been determined at this time. S/N-003 failed immediately following the 1000-hour stabilizing period. The failure mode of this unit was identical to that of S/N-001.

Final checkout of the S8DS detectors prior to starting the design verification tests at the vendor's facility demonstrated very erratic performance. Disassembly of one unit revealed cracks in the swaged gold protective tubing. The cracks were attributed to contamination originating from a ceramic sealant used to contain the insulating material inside the swaged gold tubing. Thorough analysis of these problems and the failure of the first two prototypes resulted in a complete redesign of the detector to eliminate the swaged gold tubing and the ceramic sealant, eliminate as many joints and connections as possible, and improve the design of the connector. The redesign simplifies the fabrication and improves reliability. The redesign was completed, new parts procured, and fabrication of the new units was initiated.

2. Temperature Switch

The temperature switch receives the output of the RTD's and provides signals to the controller whenever the reactor outlet coolant temperature passes outside the deadband limits as defined by two preset points.

Although performance of the S8DS design developmental switches, which were fabricated under controlled laboratory conditions, was within specification limits, the performance of the first S8DS system unit was erratic and very marginal. An effort was made to optimize the performance of this switch with the following results:

Test Condition	Setpoint Variation	Design Requirement
Ambient temperature, 50 to 120°F	6-1/2°F	±2°F
Normal Room Ambient	2°F	
Line Voltage - Regulated	1°F	
Hysteresis	4-1/2°F	1-1/2°F

In addition to the above performance characteristics, the contact closure reliability was marginal. This reliability could be improved only at the expense of additional hysteresis. Therefore, the above performance was considered to be the optimum for this design switch.

A breadboard circuit representing a fundamental design revision was fabricated and tested and showed improved performance. This approach is based on a null sensitive principle as compared to the voltage threshold operation of the current design. Test characteristics of the revised design are as follows:

Test Condition	Setpoint Stability
Ambient temperature, 50 to 120°F	±1/2°F
Line voltage ±10% variation	±1/2°F
Hysteresis	1°F maximum

This design also exhibited very positive contact closure due to the higher inherent gain. A prototype of the revised switch is being assembled and will be further tested to evaluate performance.

G. IRRADIATION TEST

The High Flux Capsule No. 10 (HF-10) experiment consists of the environmental irradiation of S8DS control-drum-drive actuators, position sensors, and shorting-bar limit switches.

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These components are being irradiated at the S8DS fast neutron dose rates at high temperature in vacuum for a period of approximately 90 days. The purpose of this test is to evaluate the effects of the combined environment on the electrical properties and operation of these components and to demonstrate that these devices will perform satisfactorily under the S8DS operational conditions.

This experiment is being performed in the 2-Mw pool reactor of the Battelle Memorial Institute, using their ion-pumped vacuum irradiation facility. The ion-pumped facility was fabricated specifically for this experiment in order to prevent organic contamination of the test components which may occur in an oil-pumped system.

An electromechanical actuator controller was fabricated for this experiment. This controller can be operated manually to cause the actuator to operate in 4-step intervals, either clockwise or counterclockwise. Each step is about 1.8° of rotation.

Figure 26 shows the test fixture that was fabricated at AI before it was shipped to BMI. The upper assembly consists of an actuator, position sensor, and a combination torque-producing, position-indicating toothed pulley wheel. The toothed pulley wheel, which is directly attached to the actuator shaft, acts in conjunction with a magnetic pickup device to serve as an auxiliary position sensor. The lower assembly is similar to the upper assembly except that two limit switches are included that are actuated by cams attached to the toothed pulley wheel. Figure 27 shows the roller of the limit switch in contact with the cam which has a 1.3° incline to its midpoint. Each switch is depressed about 30 mils.

Figure 28 shows the torque weight and toothed pulley wheel of the upper actuator assembly. The dog-leg arm which is attached to the shaft

of the position sensor fits into a slot in the pulley wheel and is held in place with a spring clip. The spring clip is designed to release at about 15 in.-oz. of torque in the event there is a bearing failure in the position sensor. In this way, the actuator can continue to operate unhindered by the position sensor.

The data cables are the same material as the S8DS cable harness. The data leads were impact-welded directly to the connector pins of the test components so that no mating connectors were necessary. Cable clamps were designed to attach directly to the test components to relieve the stress on these connections. An exception exists in the lower actuator in which the data

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Figure 26. High Flux Capsule No. 10 Test Fixture

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Figure 27. Lower Actuator Assembly

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Figure 28. Upper Actuator Assembly

lead connections were made internally, thereby eliminating the need for a connector on the component. Pig-tail leads were brought out from the stator windings and were connected to a ceramic terminal board at the top of the test fixture.

Figure 29 shows the test fixture at BMI with the thermal zone baffles and thermocouples attached. Figure 30 shows the test fixture with seven individually controlled heater zones. Before insertion into the irradiation capsule, additional thermal baffles were wrapped around the outside of each of the top six zone heaters.

The dose rates to the test components are approximately 1×10^{12} nv (E > 0.1 Mev) and

1×10^7 r/hr. The operating temperatures during irradiation are:

Actuator Stators	1000°F
Actuator Brakes	1000°F
Upper Position Sensor	800°F
Lower Position Sensor	860°F
Limit Switches	900°F

The irradiation test was initiated on August 18, 1965 and is scheduled for approximately 2200 irradiation hours. The test will be followed by final dosimetry and hot-cell examinations. All components are presently functioning satisfactorily.

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Figure 29. High Flux Test Fixture with Thermocouple Leads Attached

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Figure 30. Completed High Flux 10 Test Fixture

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VI. SNAP 8 EXPERIMENTAL REACTOR (S8ER)

A. INTRODUCTION AND SUMMARY

The objectives of the S8ER are to demonstrate reactor operation and to determine reactor performance characteristics at both 450 and 600 kwt. The tests are required to verify the SNAP 8 design and to provide experimental data upon which to base the reference design.

The S8ER fuel was removed as a unitized assembly on July 27, 1965, and transferred to the Atomic International Hot Laboratory for disassembly and examination. A screening examination of all 211 fuel elements has been completed. This phase of the fuel examination has revealed that approximately 80% of the elements had cladding failures. A detail examination and analysis of the fuel behavior is now underway.

B. DISASSEMBLY

The S8ER core was engaged with the core lifting tool (shown in Figure 31 suspended from the core removal cask) and was then withdrawn into the core removal cask. The sealed cask was transported to the AI Hot Laboratory (AIHL) where core examination was initiated. The unitized handling of the core during removal from the core vessel minimized pre-examination manipulation of core components, thereby permitting meticulous disassembly using installed equipment at the AI Hot Laboratory. Core removal was accomplished without contamination spread and with minimal radiation exposure to personnel.

In preparation for dismantling components beneath the shutdown shield, temporary shielding, 6 ft high and 2 ft thick, was erected around the containment vessel and the primary vault. A support stand for the shutdown shield, a bridge-mounted manipulator, television cameras, and lights were installed in the primary vault.

A remote control room for the manipulator, television, and lights was constructed west of the S8ER test facility, and a frame and plastic enclosure was built over the primary vault as a contamination control barrier. The shutdown shield with reactor components suspended beneath it was raised from its resting place in the containment vessel and removed to a disassembly location atop the support stand in the primary vault. Inspection of components beneath the shield was initiated using a periscope and television for viewing, and using video tape to augment photographic recording of the examination.

C. SUMMARY OF FUEL EXAMINATION RESULTS

1. Hot-Cell Data

The first phase of the S8ER core examination, the screening examination of all 211 fuel elements, was completed September 15, 1965. The fundamental purposes of this step were to evaluate the condition of the fuel elements by non-destructive examination and to provide a sound basis for the selection of a limited number of elements to be destructively examined in detail.

The screening examination of each element consisted of visual inspection employing magnification of viewing as required; measurement of diameters, length, and bow; gamma scanning; hydrogen distribution scanning; and weighing.

Visual inspection, after cleaning the elements with a Dowanol scrub, revealed cladding cracks in approximately 80% of the fuel elements. Status of the elements as determined by the visual examination is summarized in Table 18.

Figure 32 is a pictorial presentation of the core showing the location of cladding cracks observed in the screening exam.

Several types of cladding cracks were observed. Typical of these are:

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Figure 31. S8ER Lifting Tool Suspended from Core Removal Cask

a) Longitudinal cracks of up to 11 inches long and as wide as 0.040 inch, as shown in Figure 33;

b) Multiple longitudinal cracks of a lesser degree than those of item (a), as shown in Figure 34; and,

c) Longitudinal cracks at different orientations and elevations, some of which are joined by circumferential cracks, as shown in Figure 35.

In addition, three elements have circumferential cracks in the immediate vicinity of the

blind-end weld (hot end of core), one element has a sinusoidal crack running longitudinally for about 4 inches, one element has a small piece (approximately 1/8 inch by 1 inch long) of cladding attached to it which apparently was stripped from an adjacent element, and one element was broken into two separate pieces at a point about 5 inches from the top of the core.

Measurement of element diameters and bow was accomplished on a continuous readout profilometer. The data charts are now being evaluated to show amount and axial location of

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Figure 32. S8ER Reactor Core Map. Location of cladding cracks is shown by black dots. Large dot indicates a crack longer than 5 inches; small dot indicates a crack less than 5 inches long.

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Figure 33. Fuel Element With Typical Large Longitudinal Crack

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TABLE 18
STATUS OF ELEMENTS BY VISUAL INSPECTION

Core Ring	Number of Elements	Elements Cracked	
		Number	Percent
IX	42	23	55
VIII	42	33	79
VII	36	30	84
VI	30	28	93
V	24	24	100
IV	18	18	100
III	12	11	92
II	6	2	33
I	1	1	100
	211	170	80.5

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Figure 34. Fuel Element With Multiple Longitudinal Cracks (4.3X)

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Figure 35. Fuel Element Showing Longitudinal Cracks Joined by Circumferential Crack (4.3X)

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diameter changes. Length measurements were taken in a fixture employing a dial indicator and the data have been tabulated and used in preliminary statistical correlations. Element length changes for cracked and uncracked elements are tabulated by core ring in Table 19.

TABLE 19
SUMMARY OF LENGTH INCREASE

Core Ring	Clad Condition	Number of Elements	Average Increase in Element Length (in.)
IX	Cracked	23	0.020
	Uncracked	19	0.010
VIII	Cracked	33	0.027
	Uncracked	9	0.014
VII	Cracked	30	0.026
	Uncracked	6	0.007
VI	Cracked	28	0.023
	Uncracked	2	0.019
V	Cracked	24	0.022
	Uncracked	-	-
IV	Cracked	18	0.003
	Uncracked	-	-
III	Cracked	11	0.011
	Uncracked	1	-0.008
II	Cracked	2	0.014
	Uncracked	4	0.007
I	Cracked	1	0.013
	Uncracked	-	-

As shown in Table 19, the average increase in the length of elements with cracked cladding varied from two to four times that of uncracked fuel elements.

Analysis of the axial gamma scan data from the screening examination shows that the axial peak-to-average burnup distribution ranged from 1.34 to 1.41. The value used in the design calculations of the S8ER was 1.40.

The hydrogen distribution scan was an application of eddy-current inspection techniques and must be considered a developmental method in this instance. The data charts must be related to the results of hydrogen analyses to be made on fuel samples in the detailed examination.

The fuel elements were weighed after cleaning in an effort to obtain supporting data on hydrogen loss. Weight data for cracked elements is of little value because of the possible presence of NaK and Dowanol inside the elements.

Statistical studies of the fuel element as-built data and the hot laboratory screening data by ring has failed to uncover any significant correlation. Studies of the as-built data of these elements, e.g., carbon level, uranium, H/Zr, fuel rod weight, length, and diameters, have not shown any statistically significant relationship between as-built data and cladding crack frequency.

The first elements to be de-clad for detailed examination were selected on the basis of the following observations:

a) Element 432 in the core ring VIII was selected because it exhibited a length increase of 0.035 inch which was typical of elements with cracked cladding; but this element was uncracked.

b) Element 332 in core ring VIII was selected because it showed no apparent increase in fuel element length and appeared to be uncracked. Disassembly of the element proved that it was not intact as evidenced by NaK found inside the cladding. Subsequent study of the visual examination record revealed that one stereo observation had noted the possibility of a small hairline cladding crack, however, reexamination of the cladding after cutting does not reveal any failure.

c) Element 340 in core ring IX was uncracked and was selected because it showed an apparent length increase of 0.013 inch which is typical of uncracked fuel elements. It is planned to measure the ductility at elevated temperature (1400°F) of the cladding tube from this element.

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d) Element 476 in core ring VII was selected as a cracked element with a large length increase (0.059 inch).

e) Element 111 in core ring IX was selected as a cracked element which displayed a very low (0.001 inch) length increase.

The fuel rods and hydrogen barrier coatings from three of the elements noted above (432, 332, and 476) are now being visually examined.

Preliminary observations are:

a) Element 432 — The surface of the fuel rod appeared to be clean, shiny, and free from cracks, stains or discolorations. The barrier coating appears to be intact and in good condition.

b) Element 332 — The fuel rod was in four pieces and the pieces show a gradation of damage from a relatively sound appearing bottom section to a cracked upper section. The upper one-fourth of the fuel rod is cracked circumferentially and axially, as is typical with massively dehydrided fuel rods. The surface near the top is laced with numerous random small cracks. Upon decladding the element, NaK was seen to ooze from some of the cracks in the fuel rod. The barrier coating exhibits areas which have spalled off.

c) Element 476 — The fuel rod surface appeared to be in good condition but was broken into five pieces.

Most of the barrier coating appeared to be sound and of typical dark green color with the exception of the upper 2 inches along the element where there seems to be little or no coating remaining.

The reduction and correlation of dimensional data from the screening phase of the examination is underway. Extensive review of intact fuel element diameter measurements determined from readout of the profilometer charts was

initiated. Evaluation of the diameter data on the basis of the greatest reading relative to an average from the top, middle, and bottom chart traces of the intact elements shows an average local element diameter increase of 0.002 inch. It is believed that this diameter increase reflects local fuel rod diameter increases.

At the present time analyses of the data are aimed toward establishing the frequency and location of this element distortion and the magnitude of the diameter increase relative to a baseline diameter taken from the profilometer chart.

Dial indicator measurements were taken of the core grid plate surfaces. The top gridplate was found to be dish-shaped upward by about 0.024 inch and the bottom gridplate was dish-shaped downward by about 0.010 inch.

2. Operational Data

The history of hydrogen loss rate, excess reactivity, and relative fission product activity throughout S8ER power operation is summarized as follows:

The hydrogen loss rate, as defined by the observed reactivity loss rate corrected for burnup effects, increased significantly during operation as shown in Figure 36. The greatest increases occurred during the April to September 1964 time period following numerous scrams.

The excess reactivity, shown in Figure 36 normalized to equilibrium conditions at 450 kw, 1300°F outlet, 200°F ΔT , is a smooth function throughout operation within $\pm 5\%$. There is no indication of a step decrease in reactivity due to rapid hydrogen loss from one or more fuel elements during normal operation or subsequent to any of the reactor scrams.

The xenon-135 activity in the surge tank cover gas increased by a factor of about 10^3 between January 1964 and April 1965. As indicated in Figure 36, most of this increase occurred during

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TABLE 20.

RESULTS OF PRIMARY-COOLANT RADIOCHEMICAL ANALYSIS

Sample	1		2		3		4		5		6		7	
Date*	12-31-63		4-14-64		4-15-65		5-24-65		5-24-65		5-26-65		8-18-65	
Location	Primary Drain Tank		Primary Drain Tank		Circulating Primary NaK (hot sample)		Primary Drain Tank		Primary Cold Trap		Primary Drain Tank		NaK Residue in Core Vessel Dowanol	
Isotope	Activity in NaK† ($\mu\text{c/cc}$)	Fraction of Core Inventory§	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory	Activity in NaK ($\mu\text{c/cc}$)	Fraction of Core Inventory
Rb-86	~0.002	5×10^{-3}	~0.08	9×10^{-2}	0.59	0.53	-	-	-	-	-	-	-	-
Zr-95, Nb-95	~0.003	1×10^{-8}	-	-	-	-	-	-	-	-	-	-	0.61	2×10^{-5}
Ru-103	~0.001	9×10^{-8}	-	-	-	-	-	-	-	-	-	-	-	-
Cs-137	~0.0002	1×10^{-6}	-	-	2.90	1.3×10^{-3}	1.88	0.8×10^{-3}	2.30	1×10^{-3}	2.07	0.9×10^{-3}	4.9	2×10^{-3}
Cs-134	-	-	-	-	0.40	1.3×10^{-2}	0.18	6×10^{-3}	0.30	1×10^{-2}	0.19	6×10^{-3}	-	-
Sb-125	-	-	-	-	0.08	1×10^{-3}	-	-	-	-	-	-	-	-
I-131	-	-	-	-	0.81	2×10^{-5}	-	-	-	-	-	-	-	-
Ba-140, La-140	-	-	-	-	-	-	-	-	-	-	-	-	0.18	3×10^{-4}
Ce-144, Pr-144	-	-	-	-	-	-	-	-	-	-	-	-	~3.8	8×10^{-5}

*Date sample taken.

†All volumetric activities are given in microcuries per cubic centimeter of NaK.

§Fraction of core inventory in NaK.

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Figure 36. Summary of S8ER Operating History

the period June through September 1964. During this period, it was hypothesized that the increase in xenon activity was the result of cracks in a few fuel elements, based on the complete release of fuel rod surface recoils to the NaK and to the surge tank cover gas, without solubility or hold-up effects. Although a quantitative analysis of the amount of xenon that would be expected to remain in the NaK would have a large uncertainty, measurements of xenon in Na, reported by C. F. Mitra in BNL 3337, and theoretical analyses by W. C. McMillan, BNL 353 (T-63), have been extended to the S8ER conditions. From this, we can conclude, that the xenon that was seen in the surge tank sample during September 1964 to April 1965 could have been indicative of leakage from a substantial fraction of the fuel.

A total of seven primary coolant samples were taken during the S8ER test program. The results of radiochemical analyses performed on these samples are presented in Table 20. Of primary interest is the comparison of the cesium-137 activity, a fission product detected in the NaK, with the xenon-135. Both of these showed comparable increases between January 1964 and shutdown, April 1965. Since the cesium-137 should provide a good absolute indication of fission product release to the coolant, it implies that the relative xenon activity is low because of the effects described above and should be normalized to the cesium at shutdown. Therefore, the xenon increase during June to September 1964 was probably indicative of fuel element cracking. In particular, the scrams of September 1964 appear to have contributed significantly to the fuel element cracking.

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Other observations that may be made from the data presented in Table 20 are as follows:

1) The activities observed in Sample No. 1 are believed to be due to the fissioning of surface uranium contamination on the intact fuel elements or to minor cladding leakage.

2) Rubidium was present as an impurity in the coolant to the extent of approximately 5 to 15 ppm. The increased Rb^{86} activity observed in Sample No. 2 is believed to be due to increased activation of the natural rubidium impurity and Rb^{85} from the Kr^{85}

fission gas and is not quantitatively indicative of failed elements.

3) The results of Samples 3, 4, 5, and 6 illustrate the consistency of the radiochemical techniques used in the determination of cesium activities.

Evaluation of the hot laboratory examination of the S8ER fuel elements and core components will continue until the cause of cladding cracks has been determined. Various hypotheses to explain the cladding cracks have been suggested. Each of these hypotheses is being tested with the available data and each new piece of data as it becomes available to determine its validity.

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VII. SNAP 8 GROUND PROTOTYPE SYSTEM (S8DS)

A. INTRODUCTION AND SUMMARY

The current objectives of the S8DS program are: to determine the steady-state and transient performance characteristics of a SNAP 8 reactor at a variety of operating conditions including higher-than-rated power and temperature; to demonstrate satisfactory operation of the improved fuel element design and the automatic reflector control features; to develop and demonstrate techniques of automatic startup and control; to determine the nuclear and thermal operating characteristics of SNAP 8 shielding materials in a typical radiation and temperature environment; and to include the capability to test the reactor as a component of a nuclear electric power generating system.

The cold prepoisoned excess reactivity for the 5.125-inch-thick reflector was predicted as \$15.15 and new power distribution calculations confirmed previous results. S8DS reactivity lifetimes calculated for varying hydrogen loss rates showed a lifetime of greater than 10,000 hours for S8DS fuel losing hydrogen at S8ER rates. From an analysis of the effect on operating life of varying the fuel element radial gap, it was determined that an increase in the gap size offers a negligible increase in life for nominal S8DS hydrogen loss rates and a decrease in life at hydrogen loss rates greater than twice the nominal loss rates. Modifications to the cable harness remote connector are expected to result in operating temperatures of 250 to 350°F.

B. SYSTEM ANALYSIS

1. Excess Reactivity

Sixteen-group calculations were performed using a two-dimensional transport theory program to determine S8DS reactivity with the fully shimmed (5.125 inch) reflectors. Similar calculations were made for the S8ER critical assembly with full shims to provide an experimental

normalization point for the calculations. The cold, prepoisoned excess reactivity of the S8DS, predicted in this manner is \$15.15.

2. Power Distributions

Two-dimensional power distributions were obtained from the two-dimensional transport theory calculations for the S8DS with the fully shimmed reflector. The power distribution results tend to confirm previous one- and two-dimensional calculations but give greater detail. Typical radial and axial power distributions are shown in Figures 37 and 38. As can be seen from Figure 37, the radial power distribution shape does not depend strongly on the axial position.

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Figure 37. S8DS Radial Power Distributions

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Figure 38. S8DS Axial Power Distributions

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Figure 39. S8DS Reactivity vs Energy Release

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Figure 40. S8DS Lifetime vs Fuel Cladding Gap Size, Nominal Hydrogen Leakage Rate

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Figure 41. S8DS Lifetime vs Fuel Cladding Gap Size, Two Times Nominal Hydrogen Leakage Rate

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Figure 42. S8DS Lifetime vs Fuel Cladding Gap Size, Four Times Nominal Hydrogen Leakage Rate

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3. Reactivity Lifetime

Since the reactor lifetime of SNAP 8-type reactors is strongly dependent on the hydrogen loss rate, the excess reactivity of the S8DS vs energy release has been calculated for varying hydrogen loss rates. The following assumptions were included in the calculations: 600 kwtpower level, 1300°F outlet temperature, and continuous operation. Initial cold clean excess reactivity was taken as \$15.15. Figure 39 shows behavior with time of the excess reactivity for no hydrogen loss, 0.5 cc/hr (isothermal loss rate at 1400°F), 1.0 cc/hr., and the S8ER hydrogen loss rate. The excess reactivity as a function of energy release for the S8ER is shown for comparative purposes. The nuclear lifetime of the S8DS reactor with the S8ER hydrogen loss rate would be about 12,000 hours.

4. Effect of Fuel Element Radial Gap Size

A preliminary parametric study was conducted of the effect of changes in the radial hydrogen gap size on the operating lifetime of the S8DS. The gap dimension was considered to influence reactor lifetime through reactivity, fuel swelling, and phase change effects. Three hydrogen loss rates were considered for the study, a "nominal" rate corresponding to an expected S8DS loss rate, twice nominal, and four times the nominal loss rate. The reactivity and phase change lifetimes for the three hydrogen loss rates are given separately in Figures 40, 41, and 42. In addition, three values of the fuel swelling, nominal, twice nominal, and three times nominal, were plotted to show the operating lifetimes under these conditions. The study indicates that the advantage of an increased gap size is eliminated by an increase in hydrogen loss rate due to phase change effects. For the nominal loss rate case shown in Figure 40, the lifetime could be increased by an increased gap size as fuel swelling is the limiting criteria. For the greater hydrogen loss rates shown in

Figures 41 and 42, however, the influence of the higher temperature on phase change eliminates the advantages of a larger radial gap.

5. Few-Group Cross Sections

One-dimension transport calculations have been conducted to obtain few-group cross sections for use in future two-dimensional R-θ transport calculations of drum worth. The study involved running twenty-three-group transport calculations and obtaining reductions to four- and eight-group cross sections. The four- and eight-group cross sections were then used in one-dimension transport theory calculations with the reflector thickness simulating drums-in and drums-out configurations. The reactivity differences were then compared to the twenty-three-group results. The study showed the eight-group structure to be superior to the four-group structure and that there would be a negligible error introduced by using eight groups instead of twenty-three.

6. Ground Prototype Test Facility (Building 059) Radiation Levels

Calculations were made of radiation levels in the Ground Prototype Test Facility (GPTF) control room from Na²⁴ activity in the test vault. A detailed mockup of the primary loop was made to insure a realistic estimate of the dose rate. The maximum level was found to be 0.82 mrem/hr. This corresponds to a Na²⁴ inventory of 406 curies.

The dose rate in the high bay from radiative capture processes in the shield plugs during normal operation was investigated and found to be negligible. The shutdown dose rate in the test vault due to activation of iron in the pre-cast upper shield plugs was calculated to be 1.7 mrem/hr at shutdown, with a 1080-hour half-life.

The effect of a loss of mixing water from the high density concrete shield plugs was investigated. Assuming a loss of 68% of the

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original mixing water content (due to nuclear heating), the fast neutron removal cross-section will decrease from 0.110 cm^{-1} to 0.096 cm^{-1} . The resulting increase in radiation levels in working areas is summarized in Table 21.

7. Startup Analysis

A startup analysis was made using digital simulation of the reactor kinetics equations prior to sensible heat and the analog computer from sensible heat to operating temperatures. The base case constants reported in a previous analog analysis* were used as input to the UPSTART code for comparison purposes. The base case considered was a nuclear startup utilizing a 30-curie source with a 90-seconds/drum step through critical rate and a 30-seconds/drum step rate after the first power transient until deadband temperatures are reached. At this point, a final 360 seconds/drum step, long-term control rate is initiated. The drum step considered was 0.52° . Results of the analog and digital analyses are compared in Table 22.

Although the overall startup time predictions were essentially the same for both models, it is difficult to determine the reasons for the difference in predictions of peak power and temperature rates. This is currently under investigation.

Additions to the UPSTART digital code were made to improve the simulation of S8DS nuclear startup to full power. These improvements include a hot channel core heat transfer subroutine and a simulation of the primary loop NaK surge tank.

8. Cable Harness Remote Connector

The experimental and analytical work performed to determine what modifications to the connector and the facility are required in order to prevent overheating the cable harness remote connector resulted in the following improvements:

- 1) Installation of a two-layer radiation barrier between the connector and the reactor,
- 2) Redesign of connector mounting brackets to improve thermal conduction,

TABLE 21
INCREASE IN FAST NEUTRON DOSE RATES

Area	Intervening Thickness of High Density Concrete (cm)	Thickness Times Change in Cross-Section (mfp)	Fast Neutron Dose Rate for	
			$\Sigma_R = 0.110 \text{ cm}^{-1}$ $\left(\frac{\text{mrem}}{\text{hr}}\right)$	$\Sigma_R = 0.096 \text{ cm}^{-1}$ $\left(\frac{\text{mrem}}{\text{hr}}\right)$
High Bay Floor	106.7	4.40	0.00595	0.026
Control Room	122.5	5.45	0.655	3.57
Electrical Equipment Room	109.5	4.55	Negligible	Negligible
Mechanical Equipment Room	114.1	4.90	0.197	0.970
High Bay Stairwell (Top)	149.0	7.90	0.000505	0.004
High Bay Stairwell (Bottom)	61.0	2.34	1.21	2.83

*S. Birken, "Response of the SNAP 8 Reactor During Automatic Startup," NAA-SR-9646 (CRD), September 24, 1964

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TABLE 22
COMPARISON BETWEEN ANALOG AND
DIGITAL STARTUP ANALYSES

	Digital	Analog
Time to Lower Deadband Temperature, sec	5700	5900
Peak Power First Power Transient, kw	90	105
Maximum Rate of Temperature Change, °F/sec	2.2	2.6
Average Rate of Temperature Change (First Power Transient), °F/sec	1.44	1.2

3) Use of thin (approx. 0.002 inch) foils of soft copper between surfaces to improve thermal conductance,

4) Improved thermal bond between mounting brackets and containment vessel wall, and

5) Use of special high- and low-emissivity coatings on the various surfaces of the connector.

With these improvements, the temperature of the connector is expected to be between 250 and 350°F for a reactor operating condition of 600 kw, 1300°F outlet. In the nonnuclear qualification test facility, with no radiation barrier between connector and reactor, the predicted connector temperature is between 300 and 400°F.

C. REACTOR THERMOCOUPLES

Two types of thermocouple-to-pipe attachments are being considered for use on the NaK pipes located inside the GPTF vacuum chamber. Both thermocouple types are grounded and utilize Inconel sheaths and are welded to the 316 stainless-steel pipe. One of them has a 316 stainless-steel tip attached to the Inconel sheath at the grounded junction. The other has an Inconel tip. Samples of each type will be tested, including thermal cycling, to determine which is best for use on the reactor pipes.

D. NEUTRON SHIELD

Following the casting and x-ray examination of the S8DS shield, the sides and top of the stainless-steel shield vessel were plasma-spray coated with a high emissivity layer of chromic oxide (Cr_2O_3), 0.003 to 0.006 inch thick. The same coating was applied to the inside and outside of the upper head of the confinement vessel which encloses the shield vessel during the S8DS test. The lower head of the confinement vessel was not coated, but was cleaned thoroughly to minimize outgassing in the S8DS test vacuum system.

The high-temperature, radiation-resistant transducers, which will be used to detect motion of the upper head of the shield vessel if radiation-induced swelling of the lithium hydride neutron shield material occurs, were calibrated at selected temperatures up to 850°F.

E. REFLECTOR AND DRIVES

1. Beryllium Shim Emissivity Coating

Tests of the anodized coating on S8DS reflector-drum shims indicated a drop of emittance from 0.8 to 0.5 in 10,000 hours. The low emissivity could result in high reflector temperatures, so a program was conducted to evaluate alternate coatings, which under earlier testing on S10A gave small losses of emittance. One coating was a 3-phase graded plasma-sprayed Cr_2O_3 coating and the other was an aluminum phosphate dispersed chromium, nickel, and cobalt oxide spinel coating (AI-90). Samples of the 3-phase coating were prepared by three suppliers and samples of AI-90 were prepared at AI.

The samples were subjected to thermal cycling and were to be subject to 2000-hour endurance tests. All coatings spalled to some degree during thermal cycling, however, and the tests were discontinued.

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Figure 43 is a photograph of three samples after 10 thermal cycles to 1375°F at a heating rate of 19.5°F/min and cooling rate of 15°F/min to 150°F. Sample Nos. 470 and 497 were supplier-prepared samples of the 3-phase graded plasma sprayed Cr_2O_3 coating and the excessive spalling is obvious. Sample No. 521 is a control sample of the anodized beryllium and its stability is evident from the photograph. Thermal cycles at rates as low as 7°F/min were run with similar results.

Neither coating could be recommended for the S8DS, and it was concluded that at present the only "on hand" coating is the anodized coating. The emissivity of the anodized coating is expected to decrease during reactor operation.

2. Drum Bearings

The manufacture of reflector bearings resulted in a number of techniques for the production of carbon-graphite bushings. Very excellent graphite finishes have been obtained

by grinding with open grain wheels at about 3000 surface feet per minute. It has also been concluded that rough machining prior to finish sizing must be fine enough (~32 micro-inches) to obviate subsequent surface damage.

F. SYSTEM INSTRUMENTATION

1. Controller

Upon assembly of the S8DS controller, it was found that noise generated by the power switches and relay drivers interfered with the output of the time base generator and other relay drivers resulting in shortened delay periods. This noise was found to be present throughout the entire grounding system. A number of measures were taken to eliminate the problem, including the installation of more substantial ground bus bars, LC decoupling filters on the relay drivers, and capacitors for noise attenuation where permissible. After completion of these modifications, satisfactory operation of the controller was

NO. 470 AND 497 BERYLLIUM BASE
3 PHASE Cr_2O_3
COATING

NO. 521 BERYLLIUM BASE-ANODIZED

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Figure 43. High Emissivity Coating Tests, Run No. 7 - 10 Cycles

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obtained, with the exception of a malfunction which occurs during fractional first step dead-band exit operation. In further testing, a method of eliminating this problem has been devised and is being implemented.

2. Temperature Switch

One printed circuit board was completed and tested. Difficulties were encountered with temperature compensation and double closure (tendency for simultaneous closure of both high and low relay contacts). Basic design modifications will be made to correct these difficulties and improve the accuracy of the switch (Section V-F-2).

G. ASSEMBLY AND ACCEPTANCE TESTING

1. Component Acceptance Test Program

Final acceptance testing of every component is performed on each assembly as it is received from fabrication. The following tests are being performed to verify that the completed item as designed and fabricated will perform in the anticipated S8DS environment.

a. Snubber Tests

All snubber tests are performed on a clean bench in the laboratory ambient environment. These tests are designed to check (1) force to fully depress snubber, (2) force to depress plunger 0.030 inch, (3) force to depress plunger to each successive ratchet tooth, and (4) the corresponding force required to release the restraining pawl from each ratchet tooth. Figure 44 shows a snubber under test in the snubber ambient test fixture.

b. Limit Switch Tests

Limit switches are checked at laboratory ambient conditions on a clean bench for (1) contact resistance, (2) force to close contacts, (3) reduction in force to reopen contacts, (4) pretravel for switch plunger to close contacts, (5) force to depress plunger a pre-established over-travel after contacts close, and (6) the differential travel distance between

the contact closing and opening positions. Figure 45 shows a limit switch in the ambient test fixture. Upon completion of ambient environment testing, the limit switch is given an insulation resistance environmental (thermal-vacuum) test. Figure 46 shows the thermal-vacuum test fixture, with ten limit switches installed, prior to assembly into the vacuum chamber. Insulation resistance is measured with switches open and closed at ambient conditions, then at 1000°F and 10^{-5} torr. At the completion of thermal-vacuum tests, the entire ambient test sequence is repeated for reference control purposes.

c. Actuator Tests

Each actuator is subjected to the following acceptance tests performed on a clean bench at ambient laboratory conditions. (1) stator (each phase) and brake coil resistance check, (2) stator (each phase) and brake coil insulation resistance check, (3) audible noise check, (4) motor bearing friction check, (5) direction of rotation check, (6) inclined operation check, (7) end play and total indicated reading (TIR) check of shaft, (8) electrical and functional check of brake wherein the holding torque of the brake is determined, (9) starting tests which include determination of the actuators' dynamic (stepping mode) starting torque output, (10) peak torque tests wherein the maximum starting torque output is determined, and (11) torque displacement tests where the rotational displacement of the rotor is measured at torque breakaway value. Figure 47 shows an actuator coupled to the dynamometer while undergoing starting torque tests.

A step accuracy test is performed at ambient laboratory conditions with the actuators mounted in the fixture used for subsequent thermal-vacuum acceptance tests. Figure 48 shows an actuator undergoing this test. The repeatability of the angular displacement of the pointer on the scribed protractor scale per actuator step is noted. Each actuator is finally subjected to a 10-hr

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Figure 44. Ambient Testing of an S8DS Snubber

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Figure 45. Ambient Testing of a Limit Switch

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Figure 46. Thermal-Vacuum Test Fixture for Acceptance Testing of Limit Switches

environmental test to demonstrate its ability to provide rated output torques while in a vacuum of 10^{-5} torr and at temperatures up to 1025°F .

d. Scram Mechanism Tests

Figure 49 shows a scram mechanism mounted in its test fixture. The same fixture is used for ambient performance record tests and for actual thermal-vacuum acceptance testing.

The performance record test consists of:

(1) the clutch operation test which establishes the repeatability and reliability of clutch operation, (2) a drum drive test to determine the proper actuation of limit switches, and (3) the

mechanical scram test to establish the repeatability and reliability of scram cycle.

The performance record test is followed by the environmental acceptance test which is run at a 10^{-5} torr vacuum and a maximum temperature of 1000°F . The scram mechanism is wound by the fixture actuator and scrambled from the drum full-in position ten times at 5-hour intervals while test conditions are maintained.

A thermal cycle test is performed on the scram mechanism to verify its actuation capabilities after seeing a thermal shock but still under vacuum conditions.

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Figure 47. S8DS Actuator Starting Torque Test

e. Position Sensor and Demodulator Tests

Under ambient laboratory conditions, the sensors are subjected to: (1) insulation resistance tests, (2) input impedance tests, (3) output impedance tests, (4) shaft loading tests, (5) input torque tests, and (6) linear operations repeatability tests.

Under 10^{-5} torr and 800°F environmental conditions, the sensor undergoes (1) linear operations repeatability tests, (2) insulation resistance tests, and (3) input torque tests.

The demodulator acceptance tests are run at laboratory ambient conditions. Linearity and stability of the device is checked. Demodulator/

sensor combinations are checked out in pairs with the sensor in the thermal-vacuum environment and the demodulator in the laboratory environment. Tests to determine system resolution and operation stability are performed.

2. System Assembly

Reactor assembly was initiated. Figure 50 shows the initial assembly of bearing shaft hardware to a control drum. Typical helicoil inserts for hardware attachments to beryllium parts are seen in the flat back surface of the drum. The assembly support fixture with the S8DS fixed reflector attached is shown in Figure 51. A control drum is shown during early fit-up checking.

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Figure 48. S8DS Actuator Step Accuracy Test

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Figure 49. S8DS Scram Mechanism Acceptance Test

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Figure 50. S8DS Control-Drum Assembly

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Figure 51. Positioning an S8DS Control Drum to Reflector

H. TEST SUPPORT EQUIPMENT

The installation of the S8DS mechanical systems in the Ground Prototype Test Facility (GPTF, Building 059) has been completed.

Two vacuum gas holdup tanks will be installed on the exhaust line of the vacuum pumps to meet safeguards containment requirements. Each

tank will have a capacity of 10 ft³, large enough for one week of operation. The design for the installation of the two tanks has been completed.

The installation of the interconnect wiring in the control room is almost complete. All relay backpanels have been prewired and are ready for installation in the GPTF.

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