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PROGRESS REPORT
SNAP 2/10A REACTOR
APRIL-JUNE 1961
(Title Unclassified)

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PROGRESS REPORT
SNAP 2/10A REACTOR
APRIL-JUNE 1961
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Editor

W. M. HAUSSLER

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This is the first progress report in this series.

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I. PROJECT OBJECTIVES

Objectives of the SNAP 2/10A Reactor program are to:

1. Provide nuclear and mechanical design for SNAP 2/10A reactor components and associated structure.
2. Provide fuel elements for SNAP 2/10A programs.
3. Undertake research and development to increase fuel element reliability and improve fuel material properties as well as processing and fabrication techniques.
4. Conduct nuclear, heat transfer, mechanical and safety, and hazard analyses as required to ensure that reactor systems design complies with all requirements and specifications for SNAP systems.
5. Undertake appropriate component and subcomponent development and testing to ensure the availability of adequate hardware for reactor systems components.
6. Demonstrate the feasibility of the SNAP reactor concept and obtain design information through operation of SNAP reactor systems.

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II. PROGRAM SUMMARY

Reference design points for nuclear, shielding and heat transfer parameters were established and used in the continuing analyses of the reactor core design for SNAP 2/10A.

Design work for a flexible critical assembly, the SCA-4 (SNAP Critical Assembly), was initiated to study the nuclear and safety characteristics for the SNAP 2 and 10A flight system reactors.

Zero-power tests conducted on the S2-DS-1 (SNAP 2 Development System) reactor, have so far shown close correlation of design calculations with actual reactor performance.

The basic concept of the reactor reflector and control system was re-evaluated and a new 4-drum configuration adopted in order to meet the flight objectives for the SNAP 2/10A system.

The mechanical design of the reactor structure and shield for the S10A-PSM-1 (Mechanical Environmental Test APU) was established and procurement of components initiated.

Development efforts on mechanical components for the various reactor systems continued. Testing was started on two types of actuators for the control system drive and screening tests continue on bearing and spring materials as well as high temperature subcomponents such as timing devices, insulators, microswitches, and various electronic parts.

Fabrication of fuel elements for the S2DR (SNAP 2 Development Reactor) was completed and procurement initiated for fuel materials for reactors due in Fiscal Year 1962.

Process development continued on problem areas brought out by S2DR fuel processing, notably on fuel rod cracking and on fuel cladding leakage. A new technique for cladding tube closures, which is expected to considerably reduce hydrogen leakage from the fuel elements, is undergoing evaluation.

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III. REACTOR SYSTEM ANALYSIS

During this quarter the need was established for a flexible critical assembly to study the nuclear characteristics of the reactors for the SNAP 2/10A flight systems. As the reactor design progressed, it was apparent that considerable changes in the original SER (SNAP Experimental Reactor) would be necessary to meet the objectives for the SNAP flight systems. Consequently, design of a critical facility was initiated with the objectives of determining both nuclear characteristics and safety requirements for the flight system reactors. This facility, known as SCA-4, will include provisions for study of the influence of reflector height and thickness, control drum configuration and thickness, and various structural modifications to the core assembly. Detailed study of the nuclear parameters of the core continued. Overall core heights, weights, and reflector thicknesses were calculated for various excess reactivities for both the one-piece and three-piece fuel element cases. Results are shown in Figures 1 and 2. Minimum weights for the one-piece fuel element were established at core heights of 12.4 to 12.8 in. and for the three-piece element at heights of 10.4 to 10.8 in. These minimums, however, occurred at calculated k_{eff} values of 1.015 for the bare core immersed in water. In order to keep k_{eff} for the bare core in water at a value less than 1.000, the reference design points for core height were taken at 12.25 and 10.0 in. respectively for the one-piece and three-piece fuel elements. At these reference points, the thickness of the Be reflector was determined to be 2-1/8 in. for SNAP 10A and 2-1/4 in. for SNAP 2. In addition, Be shims 1/8 in. thick will allow fine reactivity adjustments in the flight reactor.

Heat transfer studies of the core continued with the general goal of limiting the maximum fuel element temperatures to the lowest possible values in order to minimize the reactivity loss due to hydrogen diffusion from the fuel. A proposed coolant flow profile for the core is shown in Figure 3. Under these conditions, the maximum fuel element temperature for the SNAP 2 core at the design operating point is 1237°F. Flow distribution through the core is achieved by the bottom grid plate assembly (Figure 4). Coolant enters the bottom plate of this assembly through the pie-shaped openings and is distributed in the plenum between the plates to emerge into the 72 flow channels surrounding the 37 fuel elements. Arrangements are currently under way to experimentally check the

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Figure 1. Weights and Heights at Various Reactivities of One-Piece Fuel Element

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Figure 2. Weights and Heights at Various Reactivities of Three-Piece Fuel Element

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Figure 3. Coolant Flow Profile

Figure 4. Bottom Grid Assembly

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coolant flow profile using the bottom grid plate assembly in the SNAP 10A flow test facility.

Shielding studies were conducted for both SNAP 2 and 10A system configurations using the FARSE code for direct beam neutrons. Shield weight was plotted against separation distance between the reactor and the dose plane. Based on this information a reference neutron shield design was selected with the dose plane located 18-1/2 ft below the top of the reactor core for SNAP 10A and 14 ft for SNAP 2. Also for SNAP 2, the CORPSE code was used to study neutron scattering from various configurations of the radiator-condenser and the NaK coolant header. Results of these studies have lead to an optimum configuration for this portion of the SNAP 2 system. The work is currently being extended to cover SNAP 10A.

At Santa Susana, the S2-DS-1 reactor was loaded with fuel and run through the following zero-power tests:

- a) Calibration of control drums and safety elements.
- b) Study of reactivity effects due to variation of hydrogen content of core and thickness of Be reflector elements.
- c) Determination of flux distribution (using uranium foil activation techniques).
- d) Initiation of low-power transients to check reactor kinetics codes used in design of the core.

Following these tests, the core vessel was sealed and the reactor system filled with NaK. Isothermal temperature coefficients and overall heat losses from the system were determined from ambient conditions to 900°F using external electrical heat.

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IV. REACTOR SYSTEM DEVELOPMENT

The design of the reactor structure and shield for the S-10A-PSM-1 was established. Fabrication of these components was initiated along with procurement of the LiH shield from ORNL. Fabrication of a revised shield casing was completed and the casing shipped to ORNL for final assembly with the LiH shield body.

Instrumentation requirements for evaluation of the reactor structure during the S-10A-PSM-1 tests were established and incorporated into the PSM-1 program.

Work began on: analysis of the temperature distribution in the S-10A shield; analysis of structural relationships between shield casing and radiator condenser in the SNAP 2 design; and evaluation of several grid plate materials for the S2/10A reactor vessel which appear to have more appropriate coefficients of thermal expansion. Design effort on the reactor reflector and drive assemblies during this quarter was concentrated on a re-evaluation of the basic design of the reflector and adoption of a 4-drum configuration as the optimum design approach. This represents a major change in the reflector design which was originally based on the use of two rotary drums for control with two spring-operated flop-out type safety elements.

The design change was engendered primarily by the stringent weight requirements established for the reflector in the SNAP 2/10A flight system as well as the severe acceleration and vibration stresses which this component will experience during launch. The new configuration is shown schematically in Figure 5. Two of the rotating drums act as coarse shims and two are used for control. The drums are held by spherically mounted bearings to avoid binding from thermal distortion or unequal thermal expansion. The beryllium reflector assembly surrounding the drums is split into two equal sections and held in place by a circumferential holding strap running around the assembly near the top. During re-entry, this strap would be cut by the melting of fusible links. The two reflector sections would then be swung away from the reactor vessel by spring action, thus insuring immediate shutdown of the reactor and complete discard of the reflector.

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Figure 5. SNAP 2/10A Core Configuration

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Redesign of the reflector structure in accord with the above concept is proceeding. Pertinent design parameters are listed below:

	<u>SNAP 10A</u>	<u>SNAP 2</u>
Reflector thickness	2-1/8 in. $\pm$ 1/8 in.	2-1/4 in. $\pm$ 1/8 in.
Reflector length	12-1/4 in.	12-1/4 in.
Individual shim thickness	1/8 in.	1/8 in.
Control drum worth	\$2.00	\$2.10
Control requirements	\$2.27	\$3.28

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V. COMPONENT DEVELOPMENT

Screening tests are under way to determine suitable bearing materials and spring materials for use in various reactor components. Bearing friction tests are being run at 1000°F and 10^{-5} mm Hg vacuum. Spring relaxation tests are running at temperatures between 800 and 1200°F under constant deflection in the apparatus shown in Figure 6. Results of the bearing tests to date are shown in Table I and of the spring relaxation tests in Table II.

High temperature tests on timing devices, microswitches, and temperature sensors are continuing. The two microswitches under test have so far successfully operated for ~3400 hr at 800°F and have undergone ~200,000 cycles without malfunction. A free-running multivibrator of TIMM components which is being considered for the first stage of an electronic timing device has so far operated for 900 hr at temperature without degradation of output. Contact has been made with the North American Aviation, Inc., Los Angeles Division to obtain maximum benefit from the Air Force HOTELEC program which developed aircraft electrical components for operation in the 600 to 750°F range. In addition, AEC approval was obtained to initiate a service contract with the General Electric Receiving Tube Division to facilitate acquisition of data and system for test of TIMM (1000°F) heaterless ceramic electronic components.

Requirements for the orbital startup programmer were drawn up and PO's issued for materials to assemble a breadboard model. A design study was started on a gas-bleed device for use as the initial startup drive for the reactor. Feasibility of the concept has been demonstrated but final evaluation of the device for this application will await the outcome of current research and development efforts on the electrically operated actuators which are also being considered for the startup drive.

Investigation of high temperature insulators and potting compounds for stator windings in actuators is continuing. Testing was started on a stepping-motor type of actuator, which will permit continuous stepping action in either direction and thus eliminate the need for an escapement mechanism on the control drive. Testing continued on winding and potting stators for the rotary solenoid type of actuator. Torque and inductance measurements on several stator windings were made.

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Figure 6. Apparatus for Spring Relaxation Tests

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TABLE I
FRICTION TEST MATERIALS AND TEST RESULTS

Test No.	Material Combinations				Observed Friction Coefficients													
	Small Rider Sample		Stationary Base Sample		Initially at Room Temp. and Pressure		After 10-20 hrs at 10-5mm Hg and Room Temp.		After 24 hrs at 10-5mm Hg and 600°F		After 24 hrs at 10-5mm Hg and 1000°F		After 7 days at 10-5mm Hg and 1000°F		Finally at Room Temp. and Pressure			
	Description	Sample Number	Description	Sample Number	Starting	Dynamic	Starting	Dynamic	Starting	Dynamic	Starting	Dynamic	Starting	Dynamic	Starting	Dynamic		
I	Ni Base - Inconel X	30	33	Ni Base - Inconel X			Equipment shakedown test. High friction samples used.											
II	WC - Kennametal K96	51	67	TiC - Ktantium K162B	†	.22	†	.65/.53	†	.68/.55	†	.64/.48	†	.78/.53	†	.71/.50		
III	Co Base-Haynes Alloy #25	5	70	Co Base-Haynes Stellite #3	†	.63/.40	†	.61/.46	†	.82/.61	†	.94/.65	†	.63/.45	†	.71		
IV	Cr ₃ C ₂ on 316 SS-Linde LC-1A	64	55	Al ₂ O ₃ on 316 SS-Linde LA-2	†	.18	†	.63/.55	†	.49	†	.43/.33	†	.37	†	.65		
V	MoS ₂ on 316 SS - Electrofilm	19	21	MoS ₂ on 316 SS-Electrofilm	†	.21	†	.36	†	.81	Stopped because of excessive friction							
VI	MoS ₂ on 316 SS - Electrofilm	20	22	MoS ₂ on 316 SS-Electrofilm	†	.20	Stopped because of excessive friction											
VII	MoS ₂ on Ni Base Alloy Electrofilm on Inconel X	31	37	MoS ₂ on Ni Base Alloy Electrofilm on Inconel X	†	.32	Stopped because of excessive friction											
VIII	MoS ₂ on Co Base Alloy Electrofilm on Haynes #25	8	74	MoS ₂ on Co Base Alloy Electrofilm on Haynes #3	†	.19	Stopped because of excessive friction											
IX	Al ₂ O ₃ on 316 SS-Linde LA-2	56	68	TiC - Ktantium K162B	†	.22	†	.33	†	.34	†	.25	†	.39	†	.89/.74		
X	Graphite-Nat'l Carbon CDJ-83	39	71	Co Base-Haynes Stellite #3	†	.18	†	.21	.27	.11	.21	.11	.47	.24	.29	.21		
XI	Al ₂ O ₃ Hot Pressed - Norton LA 687	10	48	SiC - Norton	†	.51	†	.88/.79	†	.69	†	.45/.23	†	.57/.27	†	.95/.74		
XII	BN - Carborundum Co.	1	77	Cr ₃ C ₂ - Firth CR2	.37	.23	.39	.37/.30	.53	.42/.33	.55	.40	.66	.47/.40	†	.23*		
XIII	WC - Kennametal K96	52	49	SiC - Norton	†	.50	†	.42/.25	†	.79/.71	†	.57	†	.54	†	.47/.38		
XIV	Al ₂ O ₃ Hot Pressed - Norton LA 687	9	42	Graphite - National Carbon CDJ-83	.19	.27/.21	†	.30/.22	.13	.05	.23	.20/.12	†	.09	†	.22		
XV	Cr ₃ C ₂ on 316 SS-Linde LC-1A	58	69	TiC - Ktantium K162B	†	.29	†	.42/.37	†	.48	.53	.39	.63	.43	†	.74		
XVI	Al ₂ O ₃ on 316 SS-Linde LA-2	57	72	Co Base-Haynes Stellite #3	†	.21	†	.45/.30	†	.90/.68	Stopped because of excessive friction						.85/.75	
XVII	Al ₂ O ₃ on 316 SS-Linde LA-2	16	85	Fe Base-Haynes Alloy #90	†	.16	†	.16	†	.31/.26	Equipment failure after 8 hours at 600°F							
XVIII	Al ₂ O ₃ on 316 SS-Linde LA-2	17	86	Fe Base-Haynes Alloy #90	†	.15	†	.15	†	.29/.24	(Equipment failure at 800°F, .36/.30)						†	.75/.66
XIX	C-Graphite - Graphitar #16	98	61	Al ₂ O ₃ Hot Pressed - Norton LA 687	†	.24/.20	(Special Test Overnight at 10 ⁻⁵ and 500°F, Coefficient = .16 5 hrs at 500°F & N ₂ atmosphere Coefficient = .10)											.29/.22
XX	C-Graphite - CDJ-83	90	87	Fe Base-Haynes Alloy #90	†	.20/.17	†	.22	.19	.10	†	.05	†	.18		.17**		
XXI	Al ₂ O ₃ on 316 SS-Linde LA-2	18	43	Carbon CDJ-83	†	.14	.21	.15	(Temp. raised to 1000° in one step)		†	.05	.06	.05	.17	.14		
XXII	TiC - Ktantium K162B	79	97	Fired PbO coat on 304 SS	†	.18	†	.25	†	.07	Stopped because of excessive friction							
XXIII	Al ₂ O ₃ on 316 SS-Linde LA-2	18	43	Carbon Graphite CDJ-83	†	.15	(Temp. to 1000°F in one step)				†	.05	†	.05	†	.20***		
XXIV	Deva 3-N-12	105	62	Al ₂ O ₃ Hot Pressed	†	.50/.43	.29	.23	.14	.12	.37	.21	.40	.30/.26	.48	.31		
XXV	Deva 3-F-12	108	63	Al ₂ O ₃ Hot Pressed	†	.30	†	.40	†	.26/.23	†	.21	†	.23	†	.26		

*BN showed excessive wear

**A variation in test procedure was used in this test in that after 7 days at 1000°F, a 48 hour dwell period was added. After no operation for 48 hours and with a 10⁻⁶ mm Hg pressure at 1000°F, a starting friction of .27 was observed with a subsequent dynamic or running friction of .10.

***After 3 days at 1000°F and 10⁻⁶ to 10⁻⁷ mm Hg, Ion pump was turned "on" and the diffusion pump valve was closed for 3 days. No change in friction was noted.

†Means starting friction same as running friction

.XX/.XX—Average running friction

—Maximum running friction

.XX One number means running maximum was within .05 of average running friction

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TABLE II
LOAD RELAXATION OF TORSION SPRINGS UNDER CONSTANT DEFLECTION

Material	Tensile Stress (psi)		Test Temper- ature (°F)	Load Relaxation After Elapsed Time Indicated (% of Initial Test Temperature Load)					
	At Room Temper- ature	At Test Temper- ature		100 hr	500 hr	1000 hr	2000 hr	3000 hr	4300 hr
Inconel X	55,000	41,000	1,200	29.0	40.0	47.0	-	-	-
	52,500	48,000	800	2.8	3.5	-	-	-	-
	50,000	45,400	900	1.4	5.6	6.5	-	-	-
	47,000	43,000	1,000	5.2	7.9	13.0	-	-	-
	52,000	44,600	1,000	6.3	12.0	14.6	-	-	-
	46,900	41,800	800	*0.2	*2.5	-	-	-	-
Rene 41	50,800	47,500	1,000	0.8	1.1	-	-	-	-
	-	51,000	1,100	1.0	2.0	3.1	-	-	-
	53,000	45,700	1,200	0.2	1.8	-	-	-	-
	59,000	48,000	1,200	1.6	3.5	4.8	7.2	8.9	9.5
Haynes 25	53,500	42,000	1,000	8.0	-	-	-	-	-
	29,500	23,200	1,000	1.2	-	-	-	-	-
	46,500	36,700	1,000	5.0	22.0	-	-	-	-

*This was a load cycling test and load was varied from 0 to maximum of 30 times an hour.

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Modifications were begun on the vacuum chamber in the component development laboratory to extend the capabilities of the vacuum system to 10^{-9} mm Hg and 1000°F.

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VI. FUEL DEVELOPMENT

A. FABRICATION

A total of 84 enriched fuel rods were hydrided during fabrication of the S2DR core with an overall yield of 67%. The average N_H of the rods used for the core was 6.45 with a range of 6.23 to 6.64.

Specifications for Zr sponge were prepared and a supply sufficient for GFY 1962 requirements was procured. The forecast amount of highly enriched uranium metal for GFY 1962 was also ordered.

B. RESEARCH AND DEVELOPMENT

1. Process Development

The major effort in process development was directed toward prevention of fuel rod cracking during the hydriding process. One source of hydriding cracks was eliminated through development of a triple-melting process for the fuel alloy which produces fuel rods with more uniform uranium distribution and a significantly lower impurity content. A study of the effects of extrusion parameters on crack formation was initiated after it was observed that fuel rods extruded at lower temperatures cracked less during hydriding than the higher temperature extrusions received from other vendors.

The hydriding cycle itself was examined and cracking was determined to occur primarily during the phase change portion of the cycle. An experimental investigation of the operating parameters associated with this step in the cycle has so far failed to uncover the primary cause of cracking. This work is continuing.

Study of the hydrogen leak rate at fuel element operating conditions continued. Equations were developed for hydrogen permeation through both blend and cladding of an S2DR-type fuel element. Using those equations, the overall hydrogen permeation rate for the S2DR core, operating at design conditions, was estimated to be about 1% per year. A new method for cladding tube closure through use of a thin-walled insert cap was developed and is being evaluated. Test results so far show the lowest hydrogen leak rate of any design tested. Further evaluation and refinement of this closure technique is continuing.

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2. Materials Development

Mechanical property studies of U-Zr hydride alloys were completed and a final report is in preparation. A full-size S2DR fuel element is being prepared for an irradiation test in the WTR. The test capsule is designated AI-20-1 and is designed to reach 0.05 metal at. % burnup in one year at a cladding surface temperature of 1200°F.

Disassembly of the SER core was successfully completed. All 61 fuel elements were washed and visually inspected. No gross rupture, deformation or corrosion was observed. Six elements were selected for further detailed examination in the AI CDHC (Components Development Hot Cell) and the remaining 55 were transferred to RMDF (Radioactive Materials Disposal Facility).

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