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PROGRESS REPORT
SNAP 10A
NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT
DECEMBER 1960 - MARCH 1961
(Title Unclassified)

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SNAP 10A
NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT
DECEMBER 1960 - MARCH 1961
(Title Unclassified)

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(per 7/22/82 Duff/Caudle memorandum) *HA 3/3/04*

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Atomic Energy Commission, Washington	20-24
Battelle Memorial Institute	25
Bureau of Naval Weapons	26-27
Bureau of Ships	28-29
Bureau of Yards and Docks	30
Canoga Park Area Office	31-32
Chicago Operations Office	33-34
Chicago Patent Group	35
Chief of Naval Operations	36
Director of Defense Research and Engineering (OABCW)	37
Jet Propulsion Laboratory	38-39
Lawrence Radiation Laboratory	40
Lockheed Aircraft Corp., California Division	41
Lockheed MSD, Palo Alto	42-44
Los Alamos Scientific Laboratory	45
NASA, Ames	46
NASA, Goddard	47
NASA, Langley	48
NASA, Lewis	49-50
NASA, Marshall	51-52
NASA, Washington	53-57
NASA, Western Operations Office	58
Naval Ordnance Laboratory	59
Naval Radiological Defense Laboratory	60
Naval Research Laboratory	61-62
New York Operations Office	63
Nuclear Development Corp. of America	64-65
Oak Ridge National Laboratory	66
Office of the Chief of Ordnance, DOFL	67
Office of Naval Research	68-69
Office of Technical Information Extension, USAEC, Oak Ridge, Tenn.	70-99
Project RAND	100
Power Information Center, University of Pennsylvania	101-103
Rome Air Development Center	104
School of Aviation Medicine	105
The Martin Co.	106
Wright Air Development Division	107-109
AI Library	110-150

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CONTENTS

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Project No.		Page
	Project Engineer's Report	5
2101	Safety Evaluation Studies	7
2104	System Analysis	9
2105	Design Integration	11
2130	Nuclear Analysis	13
2142	Reflector and Drive Assembly Development	15
2146	Heat Transfer System Development	17
2148	Shield Development	19
2180	Environmental Testing	21
2181	S-10-PSM-1 System Engineering	22
2190	Power Conversion System Development	23
2191	Thermoelectric Generator Materials and Process Engineering	26
2192	Thermoelectric Materials Development	28
2193	Thermoelectric Converter Process Development	30
2194	Thermoelectric Generator Development: Testing and Quality Control	32

THE TWO PREVIOUS BI-MONTHLY PROGRESS REPORTS ARE:

NAA-SR-5931	August-September 1960	Issued: January 15, 1961
NAA-SR-6023	October-November 1960	Issued: March 1, 1961

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3
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A Division of North American Aviation, Inc.
PROJECT ENGINEER'S REPORT

Program: SNAP 10A
Project Engineer: A. W. Thiele
Reporting Period: December 1960-March 1961

I. PROJECT OBJECTIVES

Upon direction from the Atomic Energy Commission the objectives of the SNAP 10A development program for a nuclear power system have been revised. This development effort will lead to flight tests under the SNAPSHOT program in conjunction with the Air Force. The revised specifications are as follows:

- A. An electrical output of at least 500 w over the system lifetime of one year.
- B. A system weight of 875 lb for the SNAPSHOT program. This weight includes approximately 100 lb for diagnostic instrumentation and other contingencies associated with the SNAPSHOT program. The weight objective for an operational SNAP 10A system is 775 lb with present day thermoelectric materials. The shield in this system will be designed to attenuate the nuclear radiation from the reactor to 10^{12} nvt of fast neutrons and 10^7 R of gamma rays per year at the payload 17-1/2 ft from the reactor.
- C. The SNAP 10A system shall utilize the SNAP 2 reactor with minimum modifications.
- D. The system will be essentially static in its operation. Power conversion will be accomplished by a thermoelectric generator coupled to the reactor heat source by means of an electromagnetically pumped liquid metal heat transfer loop.
- E. The system shall be designed to eliminate the need for active control, following orbital startup.
- F. The system will be qualified to withstand the environment imposed by the vehicle ascent and space environments.
- G. The unit must be designed to facilitate safe ground handling and launching and must be developed to contribute a minimal radiological hazard at launch to the launch facilities, personnel, and surrounding inhabitants.
- H. The power conversion subsystem shall be of a design to accommodate future growth.

II. PROJECT ENGINEER'S SUMMARY EVALUATION OF PROGRESS TO DATE

In a letter from the Atomic Energy Commission dated December 30, 1960, Atomics International was directed to terminate the bulk of its effort on the conduction-cooled SNAP 10 system configuration and to redirect its activities to the convection-cooled concept to be known as SNAP 10A. By negotiation, the specifications listed above were established for the system. The various projects within the program were re-aligned to new work statements and are working to the objectives given with the individual project progress reports.

The performance of the system was discussed with the AEC and Air Force and with Lockheed Aircraft Corp., the Air Force contractor for weapon systems with potential application for this system. On the basis of these discussions, the power level was increased from 300 to 500 w and a vehicle integration scheme

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PROJECT ENGINEER'S REPORT

was established. Lockheed released a preliminary specification to establish performance levels acceptable to their application and AI has been designing the system to these basic requirements.

The thermoelectric converter is the most critical item in the system development effort. The program is being pursued through a subcontract with General Instrument Corp. and with supporting research and development in materials and device technology at Atomics International. A design of the converter for this system has been completed and the components are under development.

Other subsystems under development include the pump, shield, startup mechanism, expansion compensator, and structure. The details of these projects are discussed under the respective subaccounts. Progress on the shield development is especially noteworthy in that a shield has been designed and placed in fabrication during the report period.

The development effort is oriented toward the S-10-PSM-1 and S-10-PSM-3 test systems. The S-10-PSM-1 system, to be used for environmental testing of the structure and components, is approaching detail design. It is scheduled to begin system testing in August 1961. Thermal and hydraulic testing will be initiated on S-10-PSM-3 in October 1961 to be followed by performance testing with the first full scale converter in the early spring in 1962.

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Program: SNAP 10A	
Project: Safety Evaluation Studies	
Responsible Engineer: F. D. Anderson	Project Engineer: A. W. Thiele
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2101

I. PROJECT OBJECTIVES

The purpose of this program is to determine through experimental and analytical studies, the possible hazards associated with the SNAP 10A unit when used for space applications. The objectives of such studies are to assure safe operation of the SNAP 10A unit throughout its operational sequence, i. e., shipment, integration, launch site operations, launch procedures, launch to orbit, and vehicle re-entry. Safety reports on the possible operational hazards will be issued and suggested solutions to such hazards will be made. This program will assist in determining the design and operating conditions for the SNAP 10A flight units in order to ensure maximum safety to operational sequence.

II. MAJOR ACCOMPLISHMENTS TO DATE

A preliminary safety analysis report has been outlined for the SNAP 10A flight of SNAPSHOT. A detailed outline has been completed and rough drafts have been completed for several of the sections.

Two codes have been written for use in calculating the gamma doses under SNAP 10A nuclear accident conditions. INSTANT, a digital code, has been written and completed. Only one decay scheme has been checked out. FIRE, a heat transfer code, has been written to study the heat transfer and temperature of a SNAP 10A core if submerged in a missile fuel fire.

Preliminary extrapolation of SNAP 2 safety analysis data to SNAP 10A conditions has been performed for inclusion in the SNAP 10A safety analysis report.

III. PROGRESS DURING REPORT PERIOD

A calculation was performed to determine reactor life and power level if SNAP 10A was not scrammed at the end of operation in orbit. These results indicated that reliable reactor shutdown at end of useful life would be necessary to assure adequate fission product decay for orbital lifetimes less than 500 yr.

A study was performed to determine the temperature of the core if submerged in a missile fuel fire. The results yielded a value of 2000°F for the mean core temperature after 680 sec in the fire.

A digital code capable of computing the gamma dose due to the instantaneous release of gross fission products or any mixture of isotopes (INSTANT) has been completed but only partially checked out.

The SNAP 10A safety criteria have been completed and will be released as part of the SNAP 10A SNAPSHOT topical report.

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Dose calculations for 20 Mw-sec and 50 Mw-sec bursts in a SNAP 10A reactor have been performed. The results indicate that personnel at 300 m distance from the excursion would receive 0.36 r from a 50 Mw-sec burst and 0.14 r from a 20 Mw-sec burst for a cloud rise of 300 m.

Investigation of the stability of ZrH and LiH has been completed by a thorough literature survey. The following conclusions can be drawn from the available information.

- 1) The properties of the hydrides are essentially equivalent to those of the metals.
- 2) Burning hydrides may react explosively when in contact with sand.
- 3) ZrH and LiH are highly pyrophoric when wet and may be immersed in water without stopping the reaction.
- 4) The stability of both hydrides is strongly dependent upon the physical size of the materials. Large masses are relatively stable.

IV. EVALUATION OF EFFORT TO DATE

The preliminary data and results for a SNAP 10A safety analysis are being obtained. The necessary codes to perform nuclear accident analysis and gamma dose calculations are being developed and obtained. None of the information necessary from outside agencies for the SNAP 10A safety analysis report has been obtained. Coordination meetings and discussions with the Pacific Missile Range Safety Group, Lockheed Systems and Missile Division, Air Force Ballistic Missile Division, and Air Force Special Weapons Center indicate that such non-nuclear information will become available for use in the SNAPSHOT safety reports. The major areas of concern, i. e., lack of information, are meteorological data, missile description, pre-launch and launch procedures, range safety procedures, and launch abort impact data.

V. NEXT REPORT PERIOD ACTIVITIES

The SNAP 10A preliminary safety analysis report will be completed. The necessary data, results, and analysis will be obtained for this report through codes, outside agency input, calculations and experimental data. The proposals from the subcontractors will be received on the various experimental studies to be performed in FY 1962.

Liaison, coordination, and review of the SNAP 10A safety program will be continued through the outside concerned agencies such as AFBMD, AFSWF, LMSD, PMR, and AEC-SNAP.

Review of the SNAP 10A safety systems and mechanisms design will continue to ensure that adequate safety is included in the SNAP 10A design for SNAPSHOT.

Program: SNAP 10A	
Project: System Analysis	
Responsible Engineer: J. L. Johnson	Project Engineer: A. W. Thiele
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2104

I. PROJECT OBJECTIVES

This project will generate the operating and performance characteristics of the SNAP 10A system using analytical techniques and current experimental information. It will perform the following activities:

- a) Optimize the operating parameters of the system to obtain maximum weight efficiency.
- b) Study the kinetic behavior of the system to establish criteria for start-up and control of the APU.
- c) Analyze nuclear and shielding requirements.
- d) Analyze nuclear hazards involved in system testing.
- e) Conduct system reliability studies.
- f) Issue system performance specifications.
- g) Analyze performance test data.

II. MAJOR ACCOMPLISHMENTS TO DATE

Requirements for the SNAP 10A flight system have been established. They are summarized below:

- a) 500-w electrical output for one year of continuous operation.
- b) Minimum radiator area.
- c) No mechanical moving parts after initial startup.
- d) Minimum output variation with respect to orbital position.
- e) Minimum package weight (objective of 775 lb).
- f) Capability to withstand missile launch environment.
- g) Minimum hazard during all phases of missile launch to operation minimum package length.
- h) Shielding to give 10^{12} nvt of fast neutrons and 10^7 r of gamma radiation integrated dose to payload.

III. PROGRESS DURING REPORT PERIOD

A preliminary design for the SNAP 10A nuclear auxiliary power source was prepared based on a pellet-type converter operating in a vacuum. Studies were conducted to compare the relative merits of several converter designs including the vacuum type, the gas encapsulated type and the swaged element type.

IV. EVALUATION OF EFFORT TO DATE

Analytical studies have shown that a system can be constructed which will meet the SNAP 10A flight objectives based on state-of-the-art performance characteristics. A radiator area requirement of 62 ft² has been established for a system having an overall efficiency of 2%. Total weight of this flight test system is expected to be in the order of 825 lb.

V. NEXT REPORT PERIOD ACTIVITIES

Optimization studies on the SNAP 10A system will be continued. System kinetic characteristics during startup and operation will be studied to generate specifications for the system design. Converter characteristics will be reviewed and system performance objectives established. Specifications for system components will be issued. Reliability apportionment will be made among components, consistent with preliminary test information regarding modes of failure and failure rates. Development programs will be monitored to maintain control of the integrated system performance.

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PROJECT PROGRESS REPORT

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Program:	SNAP 10A		
Project:	Design Integration		
Responsible Engineer:	D. B. Miller	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2105

I. PROJECT OBJECTIVES

The system design integration effort will develop the design criteria for the SNAP 10A flight system. Subsystem and component design efforts will be coordinated to provide an integrated package. Liaison will be established with the Air Force vehicle contractor to integrate the system with the vehicle.

II. MAJOR ACCOMPLISHMENTS TO DATE

A preliminary system design was completed based on the aft location in the Agena vehicle as specified by Lockheed in LMSD 1410067. Preliminary layouts and general specifications were completed on all system components. General design criteria for launch environment and performance were established.

III. PROGRESS DURING REPORT PERIOD

Early work on the system design consisted of overall configuration studies to establish the package envelope dimensions. Radiator area and shield size and location were the main influences on geometry. Preliminary sizes and weights were then transmitted to Lockheed for APU vehicle integration considerations. Package envelope dimensions are now set at a 125 in. height and a maximum diameter of 54 in.

Detailed component design was initiated in January and designs carried to a point where weight objectives for each component could be established. These are as follows:

Reactor	250 lb
Radiator Converter	100
Piping	38
NaK	17
Structure	50
Instrumentation	10
Wiring	5
Insulation	5
Expansion Compensator	12
Pumps	38
Destruct Charge	15
Shield	<u>235</u>
TOTAL for SNAPSHOT Program	775
Special Instrumentation	50
Other Test Contingencies	<u>50</u>
TOTAL for SNAPSHOT Systems	875

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Detailed system and component designs were continued on flight design to furnish a criteria package for PSM-1 system engineering (subaccount 2181).

The flight system as now envisioned consists of the reactor and pump mounted on top of a cone-shaped shield with the radiator converter and other components mounted under the shield shadow. This configuration is becoming more or less typical due to the economies in shield weight.

The reactor and controls is a SNAP 2 design amended to SNAP 10A configuration. The shield, expansion compensator, and pump are of similar design to SNAP 2 but reflect changes in design due to size and performance. The radiator-converter is of cone-shaped geometry but varies widely in detail from the other SNAP units. Forty NaK tubes carry down from an upper header to a lower one to form the cone. The thermoelectric modules and individual radiators are attached to these tubes. Each tube assembly forms a series of couples to feed into the power supply.

IV. EVALUATION OF EFFORT TO DATE

Mechanical design of the system is on schedule except for the following areas: Converter design status limits the amount of supporting mechanical design that can be done, and pump data is still scarce. If these problem areas remain the only major ones, the existing flight schedule can be maintained.

V. NEXT REPORT PERIOD ACTIVITIES

Complete system preliminary design specification and furnish to PSM-1 system engineering. Establish a test plan for flight systems that encompasses factory to flight sequence.

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Program: SNAP 10A	
Project: Nuclear Analysis	
Responsible Engineer: C. M. Podeweltz	Project Engineer: A. W. Thiele
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2130

I. PROJECT OBJECTIVES

The purpose of this project is to obtain sufficient information to permit design of an operational shield for the proposed SNAP 10A system and to provide an analytical basis for further development of the SNAP reactor concept.

To accomplish this purpose, specific objectives will be to:

- 1) Conduct studies of shielding configurations for the SNAP 10A reactor systems. These studies will include calculation from models and interpretation of relevant experimental information.
- 2) Conduct analyses of experimental results obtained during environmental testing of the SNAP 10 reactor.
- 3) Establish nuclear specifications for SNAP 10A reactor configurations.

The reactor physics program for the conduction core SNAP 10 system will be completed.

II. MAJOR ACCOMPLISHMENTS TO DATE

Experiments measuring the worth of nickel and Be end reflectors, and the gap worth between core halves have been performed on the SNAP 10 critical assembly. Radial and axial flux traverses were carried out. Analytical flux traverses and reflector worths have been calculated and are in generally good agreement with experiment. Experiments investigating the kinetic properties of the reactor and the photoneutron effect were performed. A tentative extrapolation to a full power configuration was made on the basis of critical experiment data and calculated temperature coefficients.

The thermal analysis of the finned heat rejection system and the weights associated with different parameters was completed. The dependence of shield weight on fin length was calculated for various power levels of the reactor.

Temperature coefficient experiments have been performed on the SNAP 10 critical assembly over the range of temperatures 60 to 700°F. An analysis of the data is currently in progress.

A shield has been designed for the present SNAP 10A flight configuration. Its weight is approximately 200 lb.

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III. PROGRESS DURING REPORT PERIOD

Temperature coefficient experiments have been performed on the SNAP 10 critical assembly over the range of temperatures 60 to 700°F. An analysis of the data is currently in progress.

A shield has been designed for the present SNAP 10A flight configuration. Its weight is approximately 200 lb.

IV. EVALUATION OF EFFORT TO DATE

The SNAP 10 critical experiment program has been completed. In general the agreement between experiment and analysis has been good thus far. A physics report is now being written summarizing the studies.

V. NEXT REPORT PERIOD ACTIVITIES

The physics report will be completed and issued. Further shield studies will be carried out.

NAA-SR-6294

14

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Program:	SNAP 10A		
Project:	Reflector and Drive Assembly Development		
Responsible Engineer:	R. E. Burdick	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2142

I. PROJECT OBJECTIVES

The purpose of this project is to develop the reflector and drive assembly for the SNAP 10A auxiliary power unit. The assembly will consist of control drums, control drum drive mechanism, safety elements, safety element drive mechanism, and supporting structure. The system will function in such a manner that upon receiving a signal to activate the reactor, the safety elements will be inserted to bring the reactor subcritical and the control drums will subsequently be inserted to make the reactor critical. The system will be capable of scram automatically upon re-entry and at the end of operational life. Reliability and light weight will be emphasized in the development of this system. Commercial components and available development technology will be utilized to minimize the amount of specific component development and testing required.

The reflector and drive assembly will be used to start up the APU after a successful orbit has been achieved. It must withstand vehicle launch environment and operate on command in the space environment.

II. MAJOR ACCOMPLISHMENTS TO DATE

Preliminary analysis and design have been conducted of various drive mechanism energy sources and rate control mechanisms of the SNAP 10 conduction system. The same principles were determined applicable to the SNAP 10A convection system drive mechanisms. Subsequent evaluation of the preliminary studies resulted in the direction of development effort.

III. PROGRESS DURING REPORT PERIOD

The startup drive mechanisms evaluation resulted in the recommendation of pneumatic actuation. The safety element drive mechanism actuation recommended for development effort consists of supplying gas to a variable volume container so that the buildup of pressure expands the volume resulting in physical displacement of the safety elements to a mechanically latched subcritical position. The control drum drive mechanism selected for development effort is of the same principle but operates in reverse. A variable volume container pressurized prior to launch is triggered upon ground command to release the gas. The subsequent reduction in pressure allows the spring-loaded drums to move into position to bring the reactor critical. The future flight design might allow incorporation of the two processes into a single drive mechanism.

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PROJECT PROGRESS REPORT

Alternate drive mechanisms under consideration are programmed electric motors of the type being developed on the related subaccount 2242, "SNAP 2 Reflector and Drive Assembly Development Project." If the results of the development on that project indicate compatibility with the requirements, of subaccount 2142, the use of its design could reduce the development effort of subaccount 2142.

IV. EVALUATION OF EFFORT TO DATE

The preliminary system studies which have been conducted and evaluated to date are sufficient to give direction to development effort. The development effort to date has not been of sufficient magnitude to conclusively define the type of drive mechanisms to be used in the flight hardware.

V. NEXT REPORT PERIOD ACTIVITIES

Hardware design of the various components will continue and development testing will be conducted as the hardware becomes available. Evaluation of test results will be made to determine the adequacy of components for use in the flight system. Design of the flight design hardware, based on the development results, will be initiated. Emphasis will be placed on obtaining maximum interchangeability of SNAP 10A and SNAP 2 components.

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16

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PROJECT PROGRESS REPORT

Program: SNAP 10A	
Project: Heat Transfer System Development	
Responsible Engineer: S. R. Rocklin	Project Engineer: A. W. Thiele
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2146

I. PROJECT OBJECTIVES

The objective of this project is to develop the heat transfer components required for the SNAP 10A system.

II. MAJOR ACCOMPLISHMENTS TO DATE

This project was initiated during this report period. The feasibility and preliminary design studies were accomplished under subaccount 2144.

III. PROGRESS DURING REPORT PERIOD

The primary effort during this report period was concentrated on design, fabrication, and testing of a dc electromagnetic pump using an integral source of power. This type of pump consists of a square channel with thin strips of thermoelectric material brazed to opposite walls of the channel, a short copper structure circumscribing the channel to complete the electrical path, a permanent magnet to provide the required field, and a radiator or other heat sink to establish a thermal gradient in the thermoelectric material.

An integral source NaK pump using chromel and constantan as the thermoelectric materials, designed to provide 5 gpm at 0.5 psi at a hot junction temperature of 900°F and a cold junction temperature of 710°F, has been fabricated and tested. Because test loop pressure loss at the design flow exceeded 0.5 psi, the pump could not be tested at the design point; however, the pump did produce 4.0 gpm at 0.52 psi with a temperature gradient of approximately 175°F. The discrepancy between the calculated and actual performance falls within the experimental error in the determination of the temperature gradient. It is estimated that a flight version of the test pump meeting the system requirements would weigh 30 lb.

The design and fabrication of a low-pressure drop test loop has been initiated and the instrumentation on the test pump is being refined to improve the accuracy of the temperature measurements.

IV. EVALUATION OF EFFORT TO DATE

Results of the test conducted on the integral source thermoelectric pump indicate that such a pump will meet the performance and weight requirements for the SNAP 10A system.

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PROJECT PROGRESS REPORT

V. NEXT REPORT PERIOD ACTIVITIES

The low pressure test loop will be completed and prototype integral-source and separate-source pumps will be designed, fabricated, and tested.

The design and fabrication of a hydraulic core model will be completed and hydraulic tests initiated.

An expansion compensator will be designed and fabricated.

NAA-SR-6294

18

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Program:	SNAP 10A		
Project:	Shield Development		
Responsible Engineer:	M. H. Shackelford	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2148

I. PROJECT OBJECTIVES

This project will develop a nuclear radiation shield for the SNAP 10A system. The tasks include the design and fabrication of a lithium-hydride compact and the vessel to contain this compact over missile launch and system operating conditions. This shield will be tested over the acceleration and vibration conditions and over the thermal cycle conditions of system startup.

II. MAJOR ACCOMPLISHMENTS TO DATE

A detailed design was completed and two prototype flight shields are being fabricated by the Y-12 facility at Oak Ridge. One shield will be used in the PSM-1 environmental test with the other slated for thermal testing in the PSM-3 performance test system. Containment vessels for the shields are designed and ready for fabrication.

III. PROGRESS DURING REPORT PERIOD

Shield sizes were obtained by machine analysis based on dimensions and component relationships developed under Design Integration, subaccount 2105.

Mechanical design of the containment vessel and launch support structure was then accomplished. Materials compatible with high temperature LiH were surveyed and 316 XLC selected for the first prototype testing. The vessel was designed for an initial 10 psia loading to 58 psia at operating temperatures due to cover-gas heatup and dissociation pressures. A shear strap and six side lugs hold the LiH compact during launch acceleration and vibration. When startup is achieved the temperature expansion of the compact breaks the shear strap and expands to the can wall limits.

The Y-12 facility at Oak Ridge is fabricating the first shields due to the lack of a commercial source. Facilities and experience for LiH compacting of this size are only available at Oak Ridge at the present time. A "super dry" sintering process is being used to prevent moisture from contacting the LiH during processing and reacting to lithium hydroxide. This reaction leaves free hydrogen present to evolve at operating temperature presenting a danger of over-pressure in the container.

The containment vessel will be fabricated at AI and furnished to Oak Ridge. The final assembly will be accomplished there and the finished shield shipped to AI.

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PROJECT PROGRESS REPORT

IV. EVALUATION OF EFFORT TO DATE

Completion of testing on prototype shields designed for all flight requirements will be a major accomplishment to the shield program as very little vibration or thermal testing has been done on LiH to date. Completing the design and starting fabrication is a major step towards this goal.

V. NEXT REPORT PERIOD ACTIVITIES

Completion of fabrication and test planning will comprise the next period's activities.

NAA-SR-6294

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PROJECT PROGRESS REPORT

Program:	SNAP 10A		
Project:	Environmental Testing		
Responsible Engineer:	R. M. Oliva	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2180

I. PROJECT OBJECTIVES

This project will perform tests of the SNAP 10A components under simulated non-nuclear environment. Information of failure mechanisms will be provided to the component development projects to permit redesign and qualification of the components.

II. MAJOR ACCOMPLISHMENTS TO DATE

Testing procedures for thermoelectric converter modules have been established. Tests have been completed on a couple assembly constructed from Westinghouse converter elements.

III. PROGRESS DURING REPORT PERIOD

Vibration and shock tests run to date on converter elements from the Westinghouse converter have indicated definite structural weaknesses in germanium bismuth telluride. The need for design modification of the converter module has been indicated.

IV. EVALUATION OF EFFORT TO DATE

Preliminary test parameters for vibration and shock levels have been prepared to cover both small components and large assemblies. These initial test inputs have been used in testing thermoelectric converter modules and will be used for these and other tests until such time as more definite vibration and shock input values are determined.

V. NEXT REPORT PERIOD ACTIVITIES

Tests on thermoelectric converter modules will continue. Alternate designs will be tested during this period. S-10-PSM-1 components will be tested when received.

Test planning, fixture design, and fabrication will be carried out so that the proposed test schedule for the fully assembled S-10-PSM-1 system can be met this fall.

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PROJECT PROGRESS REPORT

Program:	SNAP 10A		
Project:	S-10-PSM-1 System Engineering		
Responsible Engineer:	W. J. Hughes	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2181

I. PROJECT OBJECTIVES

The S-10-PSM-1 system will be used to develop the mechanical design criteria for the SNAP 10A flight system. This project will establish the design criteria and system design and will coordinate the test program for this system.

II. MAJOR ACCOMPLISHMENTS TO DATE

A tentative test schedule for S-10-PSM-1 system has been developed. Test procedures have been outlined and the equipment requirements identified. The component design and fabrication schedule has been developed.

III. PROGRESS DURING REPORT PERIOD

The design of components and subassemblies for the PSM-1 system test has been initiated. The overall test system configuration has been established.

The test assembly will consist of the following:

- 1) A reactor assembly with a flight prototype reactor vessel and grid plates, and a simulated core and control assembly.
- 2) A shield assembly with a flight prototype shield and containment shell.
- 3) A converter subassembly with a flight prototype structure and tubing, and a simulated converter and radiator.
- 4) A simulated pump assembly.
- 5) A flight prototype expansion compensator.
- 6) Flight prototype tubing and tubing support brackets.

IV. EVALUATION OF EFFORT TO DATE

The test program for S-10-PSM-1 has been identified, and detailed design and fabrication of the system components is proceeding in a satisfactory manner.

V. NEXT REPORT PERIOD ACTIVITIES

Component testing for S-10-PSM-1 will start in May 1961. Complete system testing is currently scheduled for August 1961.

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PROJECT PROGRESS REPORT

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Program:	SNAP 10A		
Project:	Power Conversion System Development		
Responsible Engineer:	S. R. Rocklin	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2190

I. PROJECT OBJECTIVES

The SNAP 10A system utilizes a thermoelectric converter to produce electrical power from reactor heat. It is the objective of this project to design and develop a converter capable of producing 500 w of electricity at 28 v. The converter must be capable of withstanding the vehicle launch conditions and operating in a space environment for one year with a power degradation of less than 10% during this period.

Thermoelectric devices will be built for environmental and performance test purposes and for gathering the data necessary to design and build a flight converter.

II. MAJOR ACCOMPLISHMENTS TO DATE

One-watt thermoelectric converter modules developed by Westinghouse have been tested under various conditions of temperature and nuclear radiation. These tests indicate that nuclear radiation is not a problem at SNAP 10 temperatures, but that the performance and life expectancy is materially reduced when operated at hot junction temperatures in excess of 1000°F.

A 250-w thermoelectric converter was received from Westinghouse and has been placed on test at a hot junction temperature of 980°F and cold junction temperature of 685°F.

A set of objectives for the development of a 300-w converter has been established and a program for the attainment of these objectives initiated at the General Instrument Corporation.

Because of the high radiator weight required for the SNAP 10 conduction-cooled system, a study has been initiated to determine the design and performance of a thermoelectric converter for a convection-cooled system.

III. PROGRESS DURING REPORT PERIOD

Thermoelectric Converter Design Studies

A design study has been made to investigate possible methods of producing a converter capable of meeting the SNAP 10A (convection-cooled) system. The most promising configuration appears to be one which uses state-of-the-art materials and operates in a space vacuum at a hot strap temperature of 900°F. A specification for the thermoelectric elements required for such a system has been completed and released for bid. Proposals received from various vendors based on this specification are being evaluated.

NAA-SR-6294

23

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PROJECT PROGRESS REPORT

A converter utilizing closely packed elements in a void-free configuration is being investigated as an alternate approach to the vacuum design. This converter is to be used in a two-loop system utilizing NaK for heat transfer from the reactor to the hot junctions and from the cold junction to the space radiator.

Westinghouse 250-Watt Converter Test

The Westinghouse converter has been operated for approximately 1050 hr at a hot junction temperature of 940 to 1000°F and a cold junction temperature of 670 to 700°F. During the latter part of this period, the power output has decreased from 125 w to 70 w; the resistance to ground at temperature has decreased from the order of megohms on all sections to 34×10^3 ohm in Sec. No. 1, 3.3 ohm in Sec. No. 2, 1.85 ohm in Sec. No. 3, and 4 ohm in Sec. No. 4; and the apparent internal resistance at temperature has decreased from 1.01 ohm to 0.54 ohm. The room temperature internal resistance increased from 0.25 to 0.32 ohm.

To determine the cause of the rapid degradation, one panel of the converter has been cut away and the couples in the exposed section examined. The following effects were observed:

- 1) A severe loss of material from the vicinity of the hot junction of the P-leg (GeBiTe material).
- 2) Loss of the metallurgical bond between the P-leg and the iron electrode at the hot junction so that the contact was due to the spring pressure only.
- 3) A crystalline growth between adjacent couples.
- 4) The mica insulation in the observed section appeared to be in good condition and the exposed copper cold junctions were clean and bright.

The condition of the examined couples confirms the measurements taken prior to opening the converter, that is, the apparent internal resistance decrease at temperature is caused by the shorting of couples due to the crystalline growth, and the increase in internal resistance observed at room temperature is due to the deterioration of the contacts.

A Westinghouse 2-w module has been operated for over 1000 hr in an argon atmosphere at a hot junction temperature of 900°F with a power degradation of less than 10%.

General Instruments Converter Development

The development effort at General Instruments has been reoriented to the SNAP 10A concept with the development work concentrated on the development of contacting and encapsulation techniques. Thermocouples using 'N' and 'P' PbTe elements contacted to iron by fusion bonding and encapsulated in Isomica sleeves have been fabricated and are being performance-tested at General Instruments.

IV. EVALUATION OF EFFORT TO DATE

Results of the module testing program show the need for continued emphasis on the development of encapsulation and contacting techniques.

NAA-SR-6294

24

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PROJECT PROGRESS REPORT

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V. NEXT REPORT PERIOD ACTIVITIES

The specifications for a high density converter for use in a two-loop system will be released for bid. Further design studies based on test results and aimed at increasing the performance and reliability of the converter will be undertaken.

The equipment for large scale testing of thermoelectric elements and modules will be constructed.

NAA-SR-6294

25

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PROJECT PROGRESS REPORT

Program:	SNAP 10A		
Project:	Thermoelectric Generator Materials and Process Engineering		
Responsible Engineer:	J. H. Walter	Project Engineer:	J. B. Vetrano
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2191

I. PROJECT OBJECTIVES

The objective of this project is to provide the materials engineering analysis required to reinforce the research and development phases of the SNAP 10A converter program and to ensure that the development effort will result in an engineered product. The principal efforts of this project will be:

- 1) Engineering analysis of the materials and design of the thermoelectric element and its incorporation into a reference module design.
- 2) Issuance of the materials and process specifications for the PbTe thermoelectric elements and module.
- 3) The conduct and development of certain specialized tests as required to establish the specifications.

II. MAJOR ACCOMPLISHMENTS TO DATE

The effort was initiated near the end of the reporting period, and most phases of work are just getting underway.

III. PROGRESS DURING REPORT PERIOD

A preliminary specification for PbTe pellets was written and sent to potential vendors for comment. Process specifications are being established for certain key fabrication steps based on current status information provided by the process development project.

Calculations have been initiated on the following problems:

- 1) Stresses due to bonds between dissimilar materials.
- 2) Effect of fabrication tolerances on thermocouple performance.
- 3) Effects of strengthening PbTe by adding dispersed metallic wires.

Preliminary design studies were initiated on alternate types of converters.

Eddy-current and ultrasonic measurements were taken on PbTe pellets in an effort to develop nondestructive tests for resistivity and soundness.

IV. EVALUATION OF EFFORT TO DATE

Early establishment of a specification for use in the purchase of PbTe pellets will be an important step toward achieving uniformity during processing and the

required structural integrity and converter efficiency. However, preliminary materials and processing specifications for each step in the fabrication operation will have to be written before the processing can be truly considered under control.

Some of the nondestructive tests tried appear promising for use in evaluating PbTe pellets, particularly an eddy-current test for pellet electrical resistivity. Better methods of standardization will be required to complete the evaluation of the tests.

V. NEXT REPORT PERIOD ACTIVITIES

An engineering review of the current module design, as given in the preliminary product drawing, will be made in order to establish a reference thermoelectric element design. The reference design will be evaluated to determine the physical and mechanical properties required to achieve the desired performance. Problem areas such as stress due to dissimilar material will be analyzed and specific recommendations will be made to help guide the development program. Development results will be continually fed into design analysis and the reference design will be kept current.

Materials and process specifications will be written and maintained current for the reference design and alternate designs as they are developed.

Certain specific tests will be run and evaluated as to their usefulness in determining either material or thermocouple conformance to specifications. These tests will be limited to those not performed elsewhere in the program and will include eddy-current, ultrasonic, and radiographic tests.

Program: SNAP 10A	
Project: Thermoelectric Materials Development	
Responsible Engineer: W. C. Hayes	Project Engineer: J. B. Vetrano
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2192

I. PROJECT OBJECTIVES

The project objectives are: (1) to determine the necessary physical, chemical, and mechanical properties of all materials directly associated with the thermoelectric elements; (2) to determine the behavior of these materials under specified service conditions; and (3) to develop improved materials as required by the program.

II. MAJOR ACCOMPLISHMENTS TO DATE

This project was activated on March 13, 1961.

III. PROGRESS DURING REPORT PERIOD

Several specific tasks have been initiated. These include:

- 1) Determination of properties of thermoelectric materials.
- 2) Development of analytical chemistry techniques for Pb, Te, Na, I, Fe, and O in PbTe.
- 3) Determination of thermal gradient diffusion in PbTe.
- 4) Determination of sublimation pressure of PbTe.
- 5) Development of sublimation barriers.
- 6) Development of solid state diffusion bonded and brazed electrode contacts.

Materials and equipment have been ordered. Preliminary results have been obtained in some of these areas. The expression for the vapor pressure of PbTe based on preliminary results is as follows:

$$\log p_{(\text{atm})} = \frac{-12,800}{T(^{\circ}\text{K})} + 8.82$$

At 1,000°F this gives a pressure of about 3×10^{-8} atmospheres.

A literature survey on the physical and mechanical properties of PbTe and other materials associated with the element has been completed.

Thermoelectric elements have been examined metallographically after their thermoelectric output has been measured in tests simulating service temperatures. All Fe-PbTe bonds were found to be mechanical rather than metallurgical

(limited contact with no diffusion). The hot junction bonds were found to be deteriorating rapidly in these preliminary tests. This was true of both N and P-type PbTe-Fe bonds. Deterioration of the P-type PbTe-Fe bond was more pronounced than the N-type.

IV. EVALUATION OF EFFORT TO DATE

Evaluation of preliminary results lead to the conclusions that hot-pressed bonds between PbTe and Fe (mechanical bond) may not meet the requirements for the reference design which requires both structural and thermoelectric integrity of the bond. Consequently, the materials development effort will aim at the development of a braze or diffusion-bonded junction.

V. NEXT REPORT PERIOD ACTIVITIES

Work will be continued in the following areas:

- 1) Development of brazed or diffusion bonded junction.
- 2) Development of a Cr-free Fe-based alloy diffusion barrier material which matches the coefficient of thermal expansion of PbTe.
- 3) Development of sublimation barrier material.
- 4) Evaluation of properties of thermoelectric materials.

Work in the following areas will be completed:

- 1) Development of analytical chemistry procedures.
- 2) Determination of sublimation pressures.

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PROJECT PROGRESS REPORT

Program: SNAP 10A	
Project: Thermoelectric Converter Process Development	
Responsible Engineer: M. H. Binstock	Project Engineer: J. B. Vetrano
Reporting Period: December 1960-March 1961	AEC Category: 04-10-04-10
General Order: 7580	Subaccount: 2193

I. PROJECT OBJECTIVES

The objective of this project is to develop processes for the fabrication of thermoelectric converters for use with a nuclear reactor system. To accomplish this, the project is divided into three major tasks:

- 1) Bonding of contacts to PbTe.
- 2) Encapsulating of PbTe.
- 3) Assembly of couples into modules which can be assembled into complete converters.

II. MAJOR ACCOMPLISHMENTS TO DATE

The subaccount was established in the latter part of February 1961. The major emphasis has been on establishing the facility, equipment, and material requirements, and ordering equipment and materials. Preliminary process specifications were developed.

III. PROGRESS DURING REPORT PERIOD

Bonding experiments utilizing the hot pressing technique were conducted. It was determined that metallurgical bond can be achieved between PbTe and 1015 Fe at 870°C, 4000 psi in an inert atmosphere for 30 min. It is possible by this procedure to make contacts with resistances as low as $7.5\mu - \Omega - \text{in.}^2$ but there has been very little testing performed to determine the bond integrity.

Several methods of encapsulation have been investigated. The spraying and baking on of PBX and Al-2 (ceramic enamels) looks most promising. A coated PbTe with Al-2 showed no loss in weight after 46 hr at 900°F.

Couple assembly development has consisted of brazing experiments to join the iron-clad PbTe pellets to copper to metalized BeO to stainless steel using silver alloy brazing materials. All efforts to date to join complete assemblies have not been successful, mainly due to differences of coefficient of expansion of the many materials involved.

IV. EVALUATION OF EFFORT TO DATE

The project is too new to evaluate the effort to date. It appears that the progress accomplished is satisfactory to achieve the goals of the project.

NAA-SR-6294

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V. NEXT REPORT PERIOD ACTIVITIES

- 1) Establish a facility for process development.
- 2) Purchase and install required equipment.
- 3) Continue development of hot pressing for bonding and investigate roll bonding as an alternate procedure.
- 4) Investigate electrophoresis, vapor deposition, and continue enamel coating for encapsulation.
- 5) Develop brazing techniques for joining the materials required for module assembly. Investigate use of alternate materials for better expansion coefficient match.
- 6) Develop testing and evaluating procedures for process control and analysis of product.

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Program:	SNAP 10A		
Project:	Thermoelectric Generator Development: Testing and Quality Control		
Responsible Engineer:	B. M. Watson	Project Engineer:	A. W. Thiele
Reporting Period:	December 1960-March 1961	AEC Category:	04-10-04-10
General Order:	7580	Subaccount:	2194

I. PROJECT OBJECTIVES

This project will develop and conduct electrical and thermal tests as required by the development program for thermoelectric elements and modules. Element and module quality control methods will be developed to ensure a high reliability of the final product.

II. MAJOR ACCOMPLISHMENTS TO DATE

The testing program requirements have been established.

III. PROGRESS DURING REPORT PERIOD

The specific tests necessary for the development program have been identified. Apparatus for performing these tests is being designed, fabricated, and placed in operation. A few couples have been placed on test.

A system of thermoelectric element identification and historical record maintenance has been established.

IV. EVALUATION OF EFFORT TO DATE

Design development and application of the test equipment is proceeding at a satisfactory rate. The quality control effort has not yet been activated.

V. NEXT REPORT PERIOD ACTIVITIES

An intensive test program of thermoelectric couples will be initiated. Records will be kept for each pellet throughout the processing and testing program.