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SNAP RADIOISOTOPE SPACE PROGRAMS

QUARTERLY PROGRESS REPORT NO. 7

TASK 7

April 1 through June 30, 1961

MND-P-3015-I

Approved by
Douglas G. Harvey

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FOREWORD

This quarterly report has been prepared to describe the progress of the radioisotope safety programs conducted by The Martin Company. It covers the work on Task 7 performed from April 1 through June 30, 1961 under Contract AT(30-3)-217 with the U.S. Atomic Energy Commission.

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SUMMARY

A. SUBTASK 7.1--SAFETY STUDY OF A TYPICAL CAPE CANAVERAL LAUNCH

A final safety analysis report (Ref. 1), covering the Task 9 system has been published. A safety study of the Surveyor system is in the final phases, and a preliminary report (Ref. 2) will be published during the next reporting period. A preliminary design study to better define the configuration and performance of the Surveyor generator was completed. An informal technical report (Ref. 3) will be published during the next reporting period.

B. SUBTASK 7.2--STUDY OF LUNAR IMPACT OF A RADIOISOTOPE-FUELED THERMOELECTRIC GENERATOR

An analysis to define a creditable dispersion pattern was completed. Facilities of the Canadian Armament Research and Development Establishment were investigated and found to be adequate for high velocity tests of the Surveyor generator. Detailed study results and a recommended test program are included in a final report (Ref. 4) which will be published during the next reporting period.

C. SUBTASK 7.3--UPPER ATMOSPHERE EXPERIMENTAL RE-ENTRY STUDY

Phase I and Phase II flare and telemetry capsules, designed to simulate fuel cores of nuclear auxiliary power systems, will be ejected from scientific test pods carried aloft by, and ejected from, four Atlas missiles. Sixty-four Phase I flare capsules have been manufactured, two telemetry canisters are nearing completion, and two recorder/reproducers have been functionally tested successfully.

Drawings have been completed on the Phase III SNAP 3 test generator. However, the manufacture of these test units is awaiting the assignment of test missiles. Reactor fuse link designs, which will also be used in the Phase III test program, have not been received to date.

In the fourth phase of work under this subtask, analytical studies have continued on diffusivity of various particle sizes and on the ablation phenomenon as it pertains to re-entry of radioisotope fuels.

Finally, the preliminary Air Force Special Weapons Center (AFSWC) 100-pound pod test was scheduled for launching during July. This 100-pound pod will carry two flare capsules and one telemetry capsule for optical and electronic checkout purposes prior to the launching of the Phase I and Phase II 500-pound scientific pods.

D. SUBTASK 7.4--RADIOISOTOPE SHIELDING CODE

Efforts this period have consisted primarily of routine coding, assembly and checkout operations. Arrangements have been made to obtain code input information and actual radiation levels from the Strontium-90 fueled weather station generator for a check problem to verify code calculation results.

I. INTRODUCTION

This is the fourth quarterly progress report prepared by The Martin Company, in accordance with the requirements of Contract AT(30-3)-217, specifically devoted to isotopic power systems for space applications. Task 7 is a continuing program and deals with radio-isotope flight safety analyses and tests currently under contract.

II. SUBTASK 7.1--SAFETY STUDY OF TYPICAL CAPE CANAVERAL LAUNCH*

A. OBJECTIVES

The objectives of this safety study during the quarter discussed in this report were:

- (1) To analyze the launch of SNAP-type units on the Atlantic Missile Range as to launch, ascent, and intermediate or final-stage failures.
- (2) To define the following factors for each type of failure in each type of system:
 - (a) Altitude, velocity and range.
 - (b) Forces imposed on the generator as a result of the conditions determined under Item (a).
 - (c) Final disposition of the isotope as a result of the forces determined under Item (b).

B. SCOPE AND EVALUATION

A trajectory and aerodynamic heating analysis in support of the Task 9 system was completed. By machine calculation techniques, a total of 37 various in-flight abort conditions were analyzed. A safety evaluation of a hypothetical release of isotope fuel through a launch pad fire was also conducted; this evaluation incorporated wind meteorological data, cloud formation, and maximum resulting doses. All data were included in a final safety analysis report (Ref. 1) which was submitted to the AEC. The conclusion drawn in this report is as follows:

In the preceding study, the probabilities of abort were not considered. Efforts were made to achieve some degree of conservatism by including all abort possibilities. All of the various incidents assumed have been shown by analytical and test means to result in situations of either containment of the isotope or dispersal of such a nature that no significant radiation, inhalation, or ingestion hazards would arise.

*R. J. Wilson, E. Lemanski

An analysis of the in-flight abort trajectories and subsequent drag re-entry cases, based on an original generator configuration developed for the Surveyor Program under a previous study (Ref. 5) is in the final stages. These data are being plotted and prepared for inclusion in a safety report (Ref. 2) for this system which will be submitted during the next reporting period. The most critical phases considered are listed as follows:

- (1) Maximum dynamic pressure.
- (2) Booster cutoff and subsequent sustainer failure.
- (3) Sustainer cutoff and subsequent Centaur ignition failure.
- (4) Premature thrust cutoff of the Centaur engine.
- (5) Thrust misalignment of the Centaur engine.

Explosive forces resulting from a launch pad abort have been calculated on the basis of the explosive potential of the RP-1 and LOX fuel load of the booster. Calculated overpressures are not of sufficient magnitude to be significant from the standpoint of fuel capsule integrity. The contribution of the Centaur hydrogen and LOX fuel load to the explosive forces is difficult to determine. Although several potential sources of additional data have been contacted, only meager and varied test data have been located. Because of the lack of finite data, the assumption that the percentage yield of the LOX hydrogen will be the same as that of LOX-RP-1 will be used for purposes of this study.

A preliminary study to seek an improved definition of the configuration and performance of the Surveyor Program generator was initiated during this report period. Spacecraft power demands necessitate an increase in electrical output over that used in the previous study. In addition, shielding material will be incorporated around the fuel capsule to meet the stringent radiation flux limits of the scientific payload. Incorporation of this shield material may significantly affect the re-entry and impact characteristics of the capsule. This effect has not been completely evaluated; additional machine calculation runs may be required to develop re-entry heating plots. An informal technical report (Ref. 3) summarizing the design study results will be submitted during the next reporting period. Preliminary data were presented during a briefing conducted at NASA Headquarters, Washington, in June 1961.

III. SUBTASK 7.2--STUDY OF LUNAR IMPACT OF A RADIO-ISOTOPE-FUELED THERMOELECTRIC GENERATOR*

A. OBJECTIVES

Work done under Subtask 7.2 during the last quarter of Fiscal Year 1961 grew out of the following basic objectives:

- (1) To define lunar surface and environment through a literature search.
- (2) To determine the results of impacting a generator similar to that proposed for the Surveyor Program at velocities of 500 and 9000 fps normal to the lunar surface.
- (3) To determine the consequences of fuel capsule rupture and radioactive material release following high velocity impact on the moon's surface.
- (4) To outline a test program through which to verify the analytical results determined under Items (2) and (3) and to evaluate the facilities available for conducting such a test program.

B. SCOPE AND EVALUATION

A study was conducted to determine the effects of the lunar environment on material properties such as creep rupture and fatigue stress at elevated temperatures. At temperatures of 700° C or less, evaporation rates of metals are insignificant and material properties may be predicted for normal operating conditions. The transient natures of the impact phenomena make an analytical treatment of material properties very difficult without parametric test data.

The dispersion analysis initiated late in the quarter was directed toward defining the maximum area of contamination. Impact conditions used were maximum velocity and a quartz surface although any other anticipated surface material will have a smaller compressibility factor, resulting in a deeper crater. Actual particle velocities anticipated behind the shock wave generated by the impact were evaluated to define a creditable dispersion pattern.

A visit to the Canadian Armament Research and Development Establishment (CARDE) was highly successful. The equipment available at this facility is capable of meeting test requirements for the

*R. J. Wilson, T. Dobry

7.2 program. There are at least 10 light gas guns ranging in diameter from 20 mm to 14 in. These guns are capable of firing projectiles weighing as much as 80 lb to velocities as high as 12,000 fps. Smaller masses can be propelled to velocities as high as 25,000 fps. Instrumentation capabilities of interest to this program include velocity measurements, evacuation equipment, temperature measurements of the projectile and target, and shock wave measurements. Also, it may be possible to measure impact pressure. The evacuation equipment is capable of pulling a vacuum of 1 mm Hg.

In a test program planned at this facility, it is recommended that 12 projectiles simulating the entire generator structure be fired into a quartz target at three different impact velocities. These velocities would coincide with the critical velocity of penetration, the maximum velocity resulting from failure of the retrorocket system of the surveyor vehicle, and some intermediate velocity for test correlation. The quartz target would be of sufficient size to simulate a semi-infinite slab. These tests would be conducted on a seven-in. light gas gun. A tentative schedule established with CARDE shows that these tests can be conducted early in Fiscal Year 1962. The Martin Company would supply the projectiles, designed in coordination with CARDE engineering, and the quartz targets.

Detail results of this program and a recommended test program are included in the final report (Ref. 4) of this study which will be submitted during the next reporting period; preliminary data were presented in June 1961 at NASA Headquarters.

IV. SUBTASK 7.3--UPPER ATMOSPHERE EXPERIMENTAL RE-ENTRY STUDY*

Progress on Subtask 7.3 is presented in the following sections under sub-subtask designations as follows:

- (1) Fuel core heating and ablation (7.3.1 and 7.3.2, Phases I and II).
- (2) Generator burnup (7.3.3, Phase III).
- (3) High altitude sampling (7.3.4).
- (4) Project direction and reporting (7.3.5).

A. SUB-SUBTASKS 7.3.1 AND 7.3.2--FUEL CORE HEATING AND ABLATION

1. Sub-subtask 7.3.1--Fuel Core Heating Objectives

The objective of this portion of the program is to determine the heating phenomena experienced by cores during re-entry into the earth's atmosphere following an ICBM ballistic trajectory. Specific detailed objectives are as follows:

- (1) To determine the heating rate to which a fuel core of known drag factor will be subjected when placed in an Atlas ballistic trajectory. The drag factor used in this case will be representative of the re-entry samples to be used in SNAP cores.
- (2) To design burnable fuel cores with different ballistic coefficients.
- (3) To investigate suitable dye markers or flare materials to be used in these cores.
- (4) To determine, using an IBM 709 code, the exact position and altitude at which the cores will burn up.
- (5) To design cores having identical aerodynamic parameters as those in Item (2) but having larger actual dimensions. The cores used in this case will be fitted with transmitters (supplied by AFSWC) which will sense the temperature gradient through the wall of the re-entry sample and transmit the information back to ground observer stations.

* D. J. Knighton, C. Fink, W. Hagis

- (6) To coordinate the core designs with AFSWC for incorporation in their core ejection mechanism.

2. Sub-subtask 7.3.2--Fuel Core Ablation Objectives

This portion of the program is to determine analytically, and verify experimentally, the ablation effects experienced by simulated fuel cores of nuclear auxiliary power systems during re-entry into the earth's atmosphere. In the analytical procedure used to determine the burnup of SNAP fuel cores, a mathematical model which divides the core into a series of concentric shells has been constructed. This experimental re-entry study is devoted to the verification of the accuracy of this model. Specific objectives are:

- (1) To design four fuel cores having the same external dimensions but different wall thicknesses. All cores will be designed to burn up, on the basis of an ICBM ballistic trajectory.
- (2) To design a similar core in which a transmitter is placed. This transmitter will be coupled to a temperature-sensing device and will indicate the wall temperature as a function of time during the cores re-entry into the earth's atmosphere. AFSWC will supply the sensing device and transmitter.
- (3) To coordinate with AFSWC on the design of their ejection system to accommodate these core configurations.
- (4) To determine analytically the exact position and altitude of burnup through the use of the IBM 709 ablation rate code.

In accordance with the test plan issued by the coordinating agency, AFSWC, Martin responsibilities with respect to the study include:

- (1) Design of the experiment.
- (2) Determination of initial data requirements.
- (3) Design of test capsules.
- (4) Fabrication and delivery of test packages.
- (5) Provision of ejection requirements to AFSWC.
- (6) Analysis and interpretation of data.
- (7) Provision of technical support to the Atlantic Missile Range during launch.

3. Design of Experiment

During this period the design and analysis of the test capsules for Phases I and II were completed. Engineering drawings were released to Manufacturing and, as of this report, all Phase I capsules have been completed.

a. Flare capsules

(1) Design configurations

The finalized design for the Phase I and Phase II capsules are listed in Table 1.

(2) Anticorrosion containment of alkali metals

The alkali metals to be encapsulated are, when in the liquid state, corrosive to lead. To preclude their attack, the alkali metals, excepting sodium, will be encapsulated in polypropylene containers prior to insertion in the lead capsules. Polypropylene was selected as the liner material based on tests in which it was subjected to liquid cesium, rubidium and potassium at the Dow Chemical Company. A small open-top thimble was made of polypropylene, with the same heat sealing methods that were used in actual liners. These thimbles were filled with the metal to be tested and sealed in pyrex ampules which were placed in an oven at 93° C for 55 days. The results of these tests are given in Table 2.

Corrosion tests were also performed in the Martin Corrosion Laboratory where an actual spare polypropylene liner (received from Dow Chemical) was partially filled with liquid cesium and subjected to a temperature of 66° C for a two-month period. The weight loss of the polypropylene liner was less than 0.2%.

Sodium was not corrosion tested in liners because it will not reach its melting point (97.8° C) after encapsulation.

Results of all tests conducted show that the polypropylene weight loss amounts to less than 0.2% per month. Based on this fact, the alkali metals will be safely contained for the re-entry tests which should take place this fiscal year.

(3) Plasma arc tests

During the last quarter, plasma arc tests were conducted prior to finalizing the design of the series of SNAP 3 flare capsules previously defined. The plasma arc tests, reported in Ref. 5, indicated positive results.

TABLE 1
Phase I Test Capsule Configurations

Group No.	Shape	Diameter (in.)	Height (in.)	Capsule Wall Thick- ness (in.)	Type	Flare Material	Capsule Weight (lb)	Total Weight 8 Capsules (lb)
						Weight (lb)		
1	Sphere	3	---	0.375	Na	0.16	3.51	28.08
2	Cylinder	2	5	0.375	Cs	0.15	4.60	36.80
3	Cylinder	2.5	5	0.375	Rb	0.30	6.37	50.96
4	Cylinder	3	4.5	0.375	K	0.26	7.39	59.12
								<hr/> 174.96

Phase II Test Capsule Configurations

Group No.	Shape	Diameter (in.)	Height (in.)	Capsule Wall Thick- ness (in.)	Type	Flare Material Weight (lb)	Capsule Weight (lb)	Total Weight 7 Capsules (lb)
								<hr/>
1	Cylinder	2.5	5	0.250	Na	0.44	4.7	32.90
2	Cylinder	2.5	5	0.375	K	0.17	6.2	43.40
3	Cylinder	2.5	5	0.500	Rb	0.21	7.5	52.50
4	Cylinder	2.5	5	0.625	Cs	0.14	8.5	59.50
								<hr/> 188.30

TABLE 2
Polypropylene Corrosion Tests

Length of test--55 days

Temperature--93° C

<u>Sample</u>	<u>Initial Weight (lb)</u>	<u>Final Weight (lb)</u>	<u>Weight Loss</u>	
			<u>(lb)</u>	<u>(%)</u>
(1) K	3.0546	3.0546	0	0
(2) Rb	3.0005	2.9909	0.0096	0.32
(3) Cs	2.8033	2.7972	0.0061	0.22
(4) Cs	3.2964	3.2850	0.0114	0.35
(5) Cs	3.6359	3.6280	0.0079	0.23

In general, the polypropylene ampules appeared to have suffered no adverse effects.

A group of sequentially arranged photographs, Fig. 1, demonstrates the effects of a plasma arc heat flux ($\sim 200 \text{ Btu/ft}^2\text{-sec}$) which penetrated a simulated SNAP 3 fuel core $3/8$ inch thick after only 2.7 seconds. The test core contained a void volume $1/2$ inch in diameter and $3/4$ inch long filled with pelletized sodium which clearly marked the ablation penetration of the test core. The photographs in Fig. 1 were taken at an exposure of $1/360$ second at an aperture setting of $f/2.8$.

(4) Capsule strength

Analysis of the lead capsules has revealed that each Phase I and Phase II capsule can safely support a total load of 1200 pounds. For the launch acceleration (7g) and re-entry deceleration (50g) test conditions, a maximum of 425 pounds is expected on any one capsule. Therefore, a margin of safety of 280% has been maintained in the capsule design. During handling and shipment of individually insulated and canned capsules, handling and transportation shocks up to 50g should present no structural problem.

To determine the impact resistances of the lead capsules, two Phase I, Group 4 capsules were drop tested from a height of 45 feet to a concrete surface. The capsule walls and welds passed this

a. Initial Plasma Blast

b. Ablation of Capsule

c. Penetration of Capsule Material

d. Burst of Sodium Light

Fig. 1. Plasma Arc Test--Simulated SNAP 3 Fuel Core Containing Sodium Flare

severe test successfully even though as much as a 15% material deformation was measured. Analysis shows that the impacted capsules reached a velocity of 54 fps, a deceleration of 1400 g's and an associated impact force of 9700 pounds.

(5) Delivery schedule

	<u>Mfg. Status</u>	<u>Ship to AMR</u>
Phase I--64 capsules	Completed	8-11-'61
Phase II--28 capsules	In work	8-18-'61
Phase II--56 capsules	In work	9-15-'61

The final shipment of 111 polypropylene liners containing cesium, rubidium and potassium was received from Dow Chemical in June. One set of Phases I and II dummy flare capsules (total of 8) were delivered to AFSWC for ejection system compatibility tests.

b. Telemetry canister

(1) Design configuration

The finalized design of the telemetry canister assembly was coordinated with AFSWC, after which engineering drawings were released to Manufacturing. The unit consists of a titanium (A-110 AT) cylinder whose dimensions are 9.5 inches, OD; 19-1/2 inches, length; and 0.29 inch, thickness. Twenty-six transducers are installed in its walls--3 internally and 23 on the outside surface of the canister. The transducer leads are welded to 20-gauge shielded nichrome wire which extends one foot beyond the end of the canister. Also, three 16-gauge transmitter leadout wires are potted in the wall of the canister. A fiberglass cylinder is then inserted inside the titanium canister, and a one-inch thickness of temporel insulation is poured between the fiberglass shell and the outer titanium cylinder. The completed canister subassembly and two discs of Min-K insulation are to be shipped to AFSWC for calibration of the transducers and installation of their transmitter, antennas and end plates, and a Martin-procured recorder. After a final electronic checkout of the completed telemetry capsule, AFSWC will deliver it to AMR. The total telemetry capsule design weight is 80 ± 5 pounds.

(2) Delivery schedule

<u>Telemetry Canister Unit No. 1</u>	<u>Shipping Date to AFSWC</u>
1	7-17-'61 (completed)
2	7-21-'61 (completed)
3	8-15-'61
4	9-1-'61
5*	9-15-'61
6*	9-29-'61

Thread gauges for the antenna plates and retainer rings were delivered to AFSWC in May in order that the AFSWC-provided plates and rings would be compatible with the threaded ends of the telemetry canister.

AFSWC has provided Martin with a total of 82 transducers for installation in the telemetry canisters. These elements are manufactured by Tran-sonics Corporation.

c. Recorder/reproducer

The Martin Company was authorized by the AEC to procure for and provide to AFSWC the necessary recorder/reproducers for test and installation. Consolidated Electrodynamics Corporation (CEC) was selected as the subcontractor for the development and manufacture of six units in accordance with Ref. 6.

To date, two recorder specification modifications have resulted:

- (1) The center frequency and deviation of the frequency-modulated data record amplifier were changed from 4kc to 3.6 kc, and from -40% to $\pm 40\%$, respectively, to be compatible with AFSWC transmitter requirements.

*These telemetry canisters are backup units for Phase I and Phase II tests. Upon the completion of the tests, these spare capsules will be used in the Phase III program.

- (2) The recorder start time was changed from 1 second to 7 seconds maximum.

The first change effected a redesign of the electronic circuitry; the second was simply a relaxation of the recorder specifications.

A Martin representative observed the completion of the functional testing of the first two recorders at CEC. The two recorder/reproducers were delivered to AFSWC in June for final acceptance testing. The final delivery of all recorders is expected to take place in August.

d. Re-entry test schedule and description.

For Phase I a total of 32 flare capsules, 8 of each alkali loading, and 1 telemetry capsule will be ejected from each Atlas ICBM scientific test pod. For Phase II a total of 28 flare capsules, 7 of each alkali loading, and 1 telemetry capsule will be ejected from each Atlas ICBM scientific test pod. A total of 4 missiles, 2 for each test phase, are presently scheduled for launching this fall.

So that the test capsules will be adequately dispersed, their ejection from the test pod will begin approximately 3-3/4 minutes before the re-entering pod reaches 400,000 feet. All flare capsules containing identical alkali metals will be ejected simultaneously at approximately 4 fps; ejection of the four capsule groups will occur at 25-second intervals. The telemetry capsule will be ejected 2 seconds after the last group of flare capsules is ejected.

The test pod, separated from the Atlas missile at 6 fps, will be ejected at an angular separation of about 45 degrees (from horizontal reference line). The Phase I aerodynamic drag will further displace the capsules. Ejection times and velocities were selected to provide separation of capsules consistent with the resolution levels of the observing equipment.

Detectable heating of the test capsules should begin at a descent altitude of about 250,000 feet. All flare capsules have been designed to be penetrated by re-entry heating prior to their reaching an altitude of 100,000 feet.

The scientific test pod containing the flare capsules and telemetry capsule will weigh approximately 500 pounds. This experiment will be conducted on a noninterference basis (NIB) with respect to the prime purpose of the launch.

e. Handling and storage of test articles

In order to provide safety equipment information and to acquaint all contractors and agencies participating in this program of the safe handling of the test capsules which are delivered to AFSWC and AMR, a document concerning the handling and storage of test articles has been issued. This document is submitted as Appendix A of this report.

4. Aerodynamic Re-entry Analysis

a. Heating analysis

In order to verify the original assumptions (i.e., continuum flow, laminar boundary layer, thermodynamic equilibrium) used in the heating analysis, an investigation of the various flow regimes and flow conditions encountered during capsule re-entry was made. It was found that free molecular flow exists to altitudes below 400,000 feet, but that the heating incurred during this flight regime is negligible in comparison to the heating during the slip and continuum flow regimes. The slip and continuum flow regimes extend up to altitudes of about 300,000 feet so that the heating equations based on continuum theory are applicable during the major portion of the heating regime. The assumption of continuum theory during the entire flight from 400,000 feet does incur a slight error (less than 5%) since free molecular flow and transition flow do exist during the initial phase of re-entry; however, this error is negligible.

It was also concluded that, due to the low Reynolds number and a favorable pressure gradient over the fore portions of the body, laminar flow will exist in the boundary layer during the major portion of the heating regime. Further, since the wall temperatures are always much less than the temperature for dissociation of air, the atoms of dissociated gas in the shock layer at high Mach numbers will recombine in the stream before reaching the wall. The flow can therefore be considered to be in thermochemical equilibrium.

On the basis of these conclusions (continuum flow, laminar boundary layers, thermochemical equilibrium), the use of the stagnation point heating equation derived by Detra, Kemp and Riddell to estimate the heat flux to the capsules is justified.

b. Flare capsule burnup altitude

Aerodynamic heating rates were computed for the telemetry and flare capsules using Atlas trajectory data which were obtained from Convair (Ref. 7). Each test capsule was analyzed for a complete range of expected trajectory conditions.

There are two types of re-entry trajectories: lofted and normal; and each has a dispersion allowance for the trajectory parameters at an altitude of 400,000 feet. At that altitude the lofted and normal trajectory re-entry angles vary from -21° to -27° and -16.3° to -22.3° , respectively.

The minimum altitude of burnthrough for all Phase I lead capsules was computed (Ref. 6) and presented to AFSWC during the SNAP re-entry conference at AFSWC on June 13. However, those capsules which contain the alkali metals (Cs, Rb and K) in inner polypropylene liners require additional aerodynamic heating to complete the burnup of the liner materials. To account for this the corrected minimum flare release altitudes are presently being analyzed.

The altitudes of burnthrough of the lead capsules are given in Table 3 for the Phase I capsule designs.

TABLE 3
Phase I Lead Capsule--Minimum Ablation
Penetration Altitude

<u>Specimen</u>	<u>Initial Re-entry Angle (deg)</u>	<u>Altitude (ft)</u>
Sphere: 3-in. diameter	-22	198,300
	-24	192,900
	-27	187,100
Cylinder: 2-in. diameter, 5-in. length	-22	177,000
	-24	175,300
	-27	171,300
Cylinder: 2-1/2-in. diameter, 5-in. length	-22	173,700
	-24	168,000
	-27	161,600
Cylinder: 3-in. diameter, 4-1/2-in. length	-22	167,200
	-24	164,700
	-27	150,000

5. Data Collection

A four-barrel photometer, previously planned for, will not be purchased for the program. Negotiations with the prospective suppliers were terminated when the suppliers indicated a reluctance to guarantee that their photometer would provide meaningful data under the intended conditions of use. Subsequently, it was determined that viewing conditions need not preclude good data; and it was recommended to AFSWC that a two-barrel photometer be obtained for the program if it could be aimed with an accuracy of one-half degree and operated at a favorable position within 60 nautical miles of the events to be observed.

Except for the above change the Martin optical equipment requirements, which were submitted to Convair and AFSWC in an AMR Program Requirement Document, are expected to be fulfilled.

A summary of the equipments which will be carried by the two C-54 aircraft are shown in Appendix B. The primary aircraft will be provided by AFSWC, and the secondary (telemetry) aircraft will be provided by AMR. The AFSWC and AMR manned optical equipment on Ascension Island and additional AMR, ARGMA and AFBMD telemetry, optical and radar support expected downrange on land, sea and in the air are also noted in Appendix B.

6. Flight Plan

A study was initiated to complete the aircraft flight plans for all four 500-pound pod shots. The positioning of the primary observation airplane for the night of the first firing was completed and presented at AFSWC in June. In establishing the downrange aircraft assignment an optimum aircraft position was selected so that the following conditions would exist:

- (1) On-board cameras would not look directly into the moon.
- (2) The "bright" Atlas tankage would not be in the background of the "flashing" flare capsules.
- (3) Aircraft would be positioned on a predetermined location in order that cameras could be pre-aimed as a function of the amount of dispersion in test articles that is anticipated.

In-flight data will be used to instruct the pilot of the time to be at the viewing location.

During the conference at AFSWC, new firing dates were announced, and, as a result, some of the previous effort became obsolete. It was agreed to follow a suggestion from AFSWC that primary and telemetry aircraft flight plans be formulated for the time period from September to January 1962. This work will be completed in July, and a revised flight plan will be submitted to AFSWC.

7. 100-Pound Test Pod

The AFSWC 100-pound pod will contain a telemetry capsule 8-1/8 inches in diameter and 12-5/8 inches in length (43 lb) and two flare capsules (10 lb), one of which is a 3-3/4-inch sphere containing one-fourth pound of sodium and the other, a 2-inch diameter, 4.5-inch length cylinder containing one-eighth pound of potassium. Originally, seven flare capsules were delivered to AFSWC for the test; however, weight limitations allowed the testing of only two capsules. For this test Martin delivered a titanium telemetry canister and antenna end plates, the seven flare capsules, and Min-K and Temporell insulation materials.

In addition, in order to acquaint the personnel handling the test capsules, a safe handling and storage document similar to that shown in Appendix A was prepared specifically for the 100-pound pod test payload.

The objectives of this test are these:

- (1) To determine the effects of the re-entry ionization sheath on the telemetry capsules' transmission signal (247.3 mc).
- (2) To observe optically the ablation penetration point of the two simulated SNAP 3 flare capsules.

The pod launch is expected to take place during July.

The flare capsules have been designed to be optically observed during a downrange, night-time re-entry.

B. SUB-SUBTASK 7.3.3--GENERATOR BURNUP

1. Objectives

This phase of the program is designed to determine the susceptibility of an auxiliary power unit's heterogeneous exterior con-

struction to burnup during re-entry. The objectives of this program are as follows:

- (1) To design a generator mockup of both a typical radioisotope SNAP device and a reactor SNAP device. These mockups will be designed to burn up on re-entry from an Atlas ICBM trajectory. Contained in the center of the mockups will be flare materials.
- (2) To determine analytically the exact position and altitude of burnup of these generator mockups through the use of the digital IBM 709 code.
- (3) To manufacture the mockups.
- (4) To revise the IBM 709 code for heterogeneous skins and, thereby, to refine the analytical techniques.

2. Status of Work

Design drawings of the isotope-powered SNAP test generator were completed at the end of this report period. One design consists of a mockup SNAP 3 generator which comprises an aluminum shell, a lead heat sink material, insulation, and a simulated fuel core which contains an alkali metal for purposes of optical detection. The other design uses actual SNAP 3 generator materials, except that the Haynes 25 fuel core is loaded with an alkali metal for optical detection purposes.

The mockup generators can be burned up between 400,000- and 100,000-foot altitudes using an Atlas ICBM system similar to that planned for in the Phase I and Phase II test programs. The preferred "actual" SNAP 3 test generator, using an alkali metal flare fuel, can be burned up between 400,000- and 100,000-foot altitudes by using guided rockets such as the Pershing or Scout missiles. These missiles may be launched either from NASA's Wallops Island or AMR at Cape Canaveral. One or the other of these SNAP 3 test generator designs will be used; the choice depending upon the missile, which is yet to be assigned.

This program is proceeding in accordance with the program plan for the SNAP 3 test generators. However, reactor fuse link test mock-up designs have not been initiated. A contact has been made with Atomics International, and reactor fuse link drawings have been promised for use in this program.

Launch dates on Phases I and II continue to slip, causing concern for possibility of establishing firm schedules for Phase III if scientific pods are used. This keeps this sub-subtask in a state of transience. Serious consideration is being given to planning these tests for NASA's Wallops Island facility and/or AMR, using either Pershing or Scout vehicles.

C. SUB-SUBTASK 7.3.4--HIGH ALTITUDE SAMPLING

1. Objectives

The principal objectives of this portion of the Task 7 program are:

- (1) The investigation of suitable simulated fuel materials to use in an experimental study.
- (2) A review of available high altitude sampling techniques for determining the particle size and concentration of simulated fuel after burnup has occurred.
- (3) An investigation of the feasibility of applying such methods to a program restricted to an ICBM trajectory.
- (4) The analytical determination of the limitations of such a test program in terms of concentration of fuel and the amount of fuel that must be introduced into the atmosphere.
- (5) The examination of the feasibility of measuring actual fallout of simulated fuel.
- (6) Recommendation of a test program, at the end of this phase, which will enable the actual determination of fuel particle size and dispersion in the upper atmosphere during re-entry.

2. Scope

At the start of this quarter, sampling hardware and techniques for its employment were under investigation. Particle ablation, diffusion, and fallout studies were also under way. These latter studies continued through the quarter, but the investigation of sampling hardwares and techniques was terminated, to be resumed at a later date.

At present it is felt that a large portion of the information necessary to precise definition of the biological hazards resulting from introduction of known quantities of radioactive materials into the upper

atmosphere can be stated in the following terms:

- (1) The experimentally verified analytical techniques for prediction of particulate residence time in the atmosphere as a function of particle characteristics (weight, shape, density) and altitude, latitude, and season of injection.
- (2) The experimentally verified analytical techniques for prediction of the distribution of particle characteristics as a function of material type, mode of formation and subsequent history.

In line with this thinking, current effort is concentrated on the study of diffusivity of different particle sizes in the atmosphere and on determination of the particulate size to be expected on re-entry of a fueled device. The results of these studies, coupled with those to be initiated in the next quarter on samplers, sample analysis techniques and materials for simulating radioisotope fuel, will meet the objectives for this sub-subtask and permit recommendation of a test program.

3. Sampling

Only a very modest effort was expended on this phase of the program in this quarter. It is intended that study in depth on this problem begin late in the next quarter.

a. Gummed slide

Such information as was collected on gummed slide particle collectors indicates that a large volume of air is required to obtain a measurable sample. Since large volumetric flow rates are difficult to achieve at high altitudes, this technique is questionable. However, the use of gummed collectors (1 to 2% formvar dioxane or ethylene dichloride) could prove to be adapted to fallout measurement at ground level. Such sampling is expected to prove highly important in any experiment involving release of a sample of controlled characteristics.

b. Scintillator

At present it is hoped that it will not be necessary to use a radioactive material in any controlled tests. However, if one should be used, scintillation counters could prove to be a desirable complimentary sampling technique to the sample collector. This method is promising if the detectors can be placed close enough to the initial cloud of released materials. It is assumed that, during a controlled test, the particles would be released at a specific altitude and spread out into a "cloud" from which the heavier particles would fall out immediately. If a

scintillation detector could scan this radioactive "cloud" with high resolution, the type of radiation given off could identify the material; the intensity-versus-time pattern would give an indication of the mass distribution and dispersion as a function of time. To be successful, however, the detector would have to be within an estimated two miles of the source. The angle of scanning, type of radioactive material, and time of scanning are important.

d. Impactors

The use of a rotorhute, which descends by means of rotating blades, is a method of sampling developed by Atlantic Research Corporation. The carrier rocket releases the rotorhute device above the altitude band designated for sampling. It then glides down, collecting particles by means of cascade impactors in the blades. Descent to earth (~60 fps) is faster than for a balloon and, in consequence, time for sampling is short. A major shortcoming then is that the volume of air sampled per launch vehicle used is quite low.

e. Balloons

Large plastic balloons can be obtained for sampling up to 150,000 feet. They can ascent to a predetermined altitude and remain there until a signal commands them to release their data capsule which floats to earth by means of a parachute. The large Skyhook balloons displacing 9×10^6 cubic feet of air can ascend to 150,000 feet with over 100 pounds of payload. Smaller ones can ascend to 100,000 feet with 200 pounds payload and remain there for eight hours. It is estimated that a balloon launch and capsule recovery could be accomplished for \$15,000, including the price of equipment involved. It should be noted that balloons can be considered for placement of the test sample at the desired altitude for controlled sample experiments.

4. Ablation

Early in the quarter, studies were undertaken to determine the distribution of particle sizes expected to be generated on re-entry. This information is necessary to properly evaluate samplers and to select a test sample material. The early results of this study (reported in Ref. 9) are soon to be revised. The phenomenon of large particle breakup discussed in Ref. 9 can be best likened to cell division in animals. Further analysis has indicated that the breakup is more like that demonstrated in air stream tests of droplets; the Reynolds numbers are quite comparable. The small particles thus generated (diameter less than mean free path in the medium) are subject to stagnation heating while the larger particles are expected to generate a shock wave and be further ablated by the high temperatures existing behind it.

A digital computer program is being prepared to solve the re-entry heating equations for small particles. It is assumed that the isotopic fuel is a molten mass on penetration of its cladding. A mass of liquid metal is dumped and sprayed into the atmosphere on penetration. The mass of liquid will break up into small drops which will either burn up completely or be brought to rest due to the resistance of the atmosphere. It is desired to know what will be the resulting distribution of particles in the atmosphere as a function of altitude.

It is anticipated that the original mass of liquid will rapidly break up into relatively small particles (500 microns), and, hence, only two mechanisms of particle formation are considered: condensation of the gases of ablation and particles which remain after ablation.

As a first approach to the determination of final particle size it was assumed that the equations for particle ablation and drag force hold and that there is no combustion of the mass and no heat loss through radiation. The equations of motion were written and solved by an approximate analytical technique (perturbation), and reasonable results were obtained. To evaluate the validity of the approximate solution, a numerical solution of the equations is being carried out.

To arrive at a more realistic approach, terms for combustion and decay heating have been included in the equations. Re-entry heating includes burning (combination with oxygen) which supplies considerable heat to the process, with a resultant effect on particle size and subsequent dispersion rates. If the equations for the ablation process are accurate, it will be possible to predict the distribution of the gases in the atmosphere. These will presumably condense into a cloud of solid particles. The process of nucleation of this gas is being studied to find a means for predicting the size of the particles after condensation. For the case of a gas whose concentration remains essentially constant, the distribution of particle sizes upon condensation can be determined. For the case at hand, however, the concentration is decreasing and this fact must be taken into account.

5. Diffusion

Study in this period continued on analytical procedures for predicting the diffusivity of small particles in a varied atmosphere.

Metrological data are being collected but are in short supply for a large area of interest--100,000- to 250,000-foot altitudes. Whenever a distribution of different-size particles is released in a still atmosphere, the larger particles (above 50 microns in diameter), if sufficiently dense,

begin to fall to earth with a velocity of the order of 12 cm/sec. These particles can diffuse only if the medium is in a state of turbulence. The prediction of the time when these heavy particles will fall out is possible when wind profiles are obtained. Wind speed and direction are needed for at least every 5000-foot increment to the altitude of release. The fall speed of a particle of a certain size and the time that it will remain in each layer can be calculated. Using this time and the wind velocity for the layer it is possible to predict how far the particle is carried in the layer and in which direction. These distances, represented by vectors for each layer and drawn head to tail on a map, give the predicted fall-out position of the certain particle.

Particles below about 20 microns in diameter tend to spread out (from regions of high concentrations to regions of lower concentrations) according to the diffusion equation and the degree of turbulence present.

Two sample sources are of interest in this study:

- (1) The instantaneous point source such as would be the case when a distribution of particles is sent up by rocket or balloon and spread by explosion from a point. This situation could exist in a controlled test.
- (2) The instantaneous line source, such as the case when the distribution of particles is released from a rocket as it moves along its trajectory. The following equations apply only for particles below about 20 microns in diameter.

a. Point source

A solution of the diffusion equation

$$\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} = \frac{1}{D} \frac{\partial C}{\partial t} \quad (1)$$

is given by Ref. 13 as

$$C(x, y, z, t) = \frac{M}{(4\pi t)^{3/2} (D_x D_y D_z)^{1/2}} \exp \left[-\frac{1}{4t} \left(\frac{x^2}{D_x} + \frac{y^2}{D_y} + \frac{z^2}{D_z} \right) \right] \quad (2)$$

where

x, y, z = coordinates of point at which the concentration is taken

t = time

D_x, D_y, D_z = diffusion coefficients (assumed constant) in the coordinate directions (cm^2/sec)

C = concentration (gm/m^3 or $\text{particles}/\text{m}^3$)

M = initial amount of material (gm).

For isentropic diffusion,

$$D = D_x = D_y = D_z$$

and the symmetry is spherical; the equation becomes

$$C(x, y, z, t) = \frac{M}{8 (\pi Dt)^{3/2}} \exp \left[-\frac{r^2}{4 Dt} \right] \quad (3)$$

$$r^2 = x^2 + y^2 + z^2$$

This equation gives the concentration at any point, at any time, for small particles in an infinite medium. The diffusion coefficient D depends upon the turbulence in the air and is proportional to the velocity of the particles through the air. The exponent in Eq (3) is very sensitive when D is changed; therefore, only a small range of values for D is allowable for each velocity and time. The concentration falls off very rapidly with distance due to the r^2 term in the exponent.

b. Line source

If the point source equation is integrated with respect to some direction (usually the Y direction), the equation for a line source in an infinite medium is obtained:

$$C(x, z, t) = \frac{M}{4\pi Dt} \exp \left[-\frac{r^2}{4 Dt} \right] \quad (4)$$

where

$$r^2 = x^2 + z^2$$

and the line source is in the Y direction. The particles diffuse outward

in a cylindrical pattern with the line source as its axis, slow down and come to an equilibrium velocity (a function of the temperature of the medium).

6. Plans for Next Quarter

It is expected that the ablation and diffusion studies will have progressed sufficiently in the next quarter to provide the necessary tools for completion of this sub-subtask. At present, it is planned to terminate these studies about September 1 and start work in the following areas:

- (1) Sampler--applicability of types, definition of characteristics such as flow rate, efficiency as a function of particle size, etc.
- (2) Test materials--analysis of materials for use as simulated core materials.
- (3) Sample analysis--applicable analysis methods as functions of test material, particle size, mass, etc.
- (4) Sample placement--investigation in depth of means whereby samples and collectors would be placed at altitude.

D. SUB-SUBTASK 7.3.5--PROJECT DIRECTION AND REPORTING

1. Objectives

The effort required to administer the total Subtask 7.3 is included in this sub-subtask. Specifically, the following work is to be accomplished:

- (1) A literature search of high altitude flare materials.
- (2) Project direction of the analytical, design, manufacturing and report phases of sub-subtasks 7.3.1, 7.3.2, 7.3.3 and 7.3.4.
- (3) Technical liaison and coordination with the various Government agencies involved in this program; specifically, the agencies to be contacted are NASA, AFSWC, Hq ARDC, Convair, AFEMD, AMR, and the AEC.
- (4) All reports prepared in the execution of the 7.3 program will be charged to this sub-subtask.

2. Status of Work

Reporting during this quarter has consisted of monthly letters (Refs. 9, 10, 11), and a quarterly progress report (Ref. 5).

Project effort has been devoted to maintaining the various tasks on schedule and assuring proper coordination of contractor efforts with those of affected government agencies. A documentary movie and slides for Sub-subtasks 7.3.1 and 7.3.2 are in progress.

Martin representatives attended the SNAP Re-entry Test Program coordination meeting held at KAFB on June 13 and 14, 1961. This meeting revealed excellent progress for all areas of work for the first five months of this year. One highlight of this meeting was the announcement that the Martin optical equipment requirements for the AFSWC-AMR aircraft are expected to be fulfilled.

All phases of work are progressing satisfactorily, except for the design drawing preparation for the Sub-subtask 7.3.3 reactor test unit. Reactor test unit drawings are held up, pending the receipt of AI reactor fuse link designs.

It has become apparent, from the problems of launching delays and noninterference basis (NIB) testing which has been encountered in Sub-subtasks 7.3.1 and 7.3.2 test programs, that primary test vehicles such as the Pershing or Scout should be assigned for the Sub-subtask 7.3.3 tests.

V. SUBTASK 7.4--RADIOISOTOPE SHIELDING CODE*

A. OBJECTIVES

The objectives of this program are:

- (1) To develop a machine calculation code using the Monte Carlo technique to accomplish the following:
 - (a) To determine the gamma flux in photons/cm²-sec or dose rates in mr/hr for a given shield configuration.
 - (b) To determine through an iterative process the shielding necessary to reduce radiation dosage to any selected value (between the range of maximum emission and one photon/cm²-sec) when measured at any selected distance from 2.5 centimeters to 30 meters from the external surface of the shield.
- (2) To utilize the code to calculate the dose rate of one fueled generator for comparison with actual measurements.

B. SCOPE AND EVALUATION

This Monte Carlo code is designed to compute the gamma dose and flux for each energy group in certain prespecified volumes. Items of information for code input, answers computed by the code, and flow diagrams were included in the last quarterly report (Ref. 5). Efforts this period have consisted primarily of routine coding, assembly and checkout operations using the IBM 7090 calculating facilities. The following subroutines have been checked out or are in the process of being checked out: ANAEST, GNOB, RANNO, MFPATH, BORN, XSECT, CMONTE, PAIRPR, COORDA, COORDX and KNSCAT. The remaining subroutines as well as the main control program are in the coding process. Delays in the code checkout phase of the program have been caused by two factors:

- (1) Calculation facilities were changed from IBM 709 to IBM 7090.
- (2) All calculation services were consolidated at a separate facility.

* M. Kniedler

Although this consolidated arrangement will be more efficient for the running of established programs, the advanced scheduling procedure currently in effect and the physical separation of engineering and calculation facilities have increased the time required for checkout operations.

Plans to develop input information for a check problem to verify code calculation results have been completed, and approximately 50% of the data are available. The weather station generator developed under Task 1 of Contract AT(30-1)-2519 is being used as the model for this problem. This unit was initially fueled with approximately 17,500 curies of Strontium-90 and 3000 curies of Strontium-89. A radiation survey to provide the verification data will be conducted in September prior to delivery and shipment of the unit. Preparation of a final report on this program is expected to be complete late in the next reporting period.

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APPENDIX A

HANDLING AND STORAGE OF TEST ARTICLES AEC UPPER ATMOSPHERE RE-ENTRY PROGRAM

I. TEST ARTICLES

The subject test articles consist of a total of six titanium telemetry canisters, one per launch, and a total of 148 lead capsules, 32 for each Phase I launch and 28 for each Phase II launch.

II. HANDLING AND STORAGE OF TELEMETRY CANISTERS

The telemetry canisters contain sensitive electronic equipment and should be handled in a manner so as to prevent damage from physical shock. Storage until use should be at a temperature below 40° C.

III. HANDLING AND STORAGE OF LEAD CAPSULES

A typical sealed lead capsule (wall thickness 3/8 inch to 5/8 inch) contains an inner sealed polypropylene cylinder in an inert (argon) atmosphere which, in turn, contains the cesium, rubidium, or potassium in an inert (argon) atmosphere. The sodium metal is contained in only lead capsules having a wall thickness ranging from 1/4 to 3/8 inch. In addition, to avoid damage during shipment, the lead capsules are doubly contained in shipping tins and wood crates.

The flare capsules are not hazardous insofar as shock and electromagnetic interference are concerned. A hazard exists only if a capsule is ruptured.

A. PACKAGING FOR SHIPMENT

Prior to shipment each lead capsule will be placed in a vermiculite-lined metal can, the can solder-sealed to exclude moisture. On crating for shipment, individual cans will be separated by additional vermiculite to prevent in-transit damage.

B. UNPACKING ON RECEIPT

Care should be taken, in all handling operations, not to rupture the lead capsules.

After removal from the packing crates the sealed cans should be examined for external damage which might possibly have resulted in damage to the contained lead capsules. Damaged lead capsules should be removed to a remote area and burned under adequate control.

Undamaged cans should be opened by mechanical means. Heat should not be used. The lead capsules may now be removed from the cans and loaded into the scientific test pod.

If it is necessary to transport the lead capsules to the test pod assembly area, a wheeled, closed, compartmented vehicle should be used.

C. STORAGE

The lead capsules should be stored in a cool, dry area until used. Storage temperatures should not exceed 40° C.* The melting points of the alkali metals are listed below.

<u>Alkali Metals</u>	<u>Melting Point (°C)</u>
Cesium	28.5
Rubidium	38.5
Potassium	62.3
Sodium	97.8

D. PROTECTIVE CLOTHING

This is a precautionary measure.

During unpacking and all subsequent handling, personnel involved should be provided with face shields and fire retardant clothing.

*Pod on launch pad shall be covered by a canvas sun shield or air cooled, if necessary, to meet the above requirement.

E. FIRE FIGHTING

This is a precautionary measure.

A supply of powdered graphite, metal-x or G-1 powder should be available in the storage and handling areas. These materials should be stored in covered containers to prevent contamination by moisture. Long handled shovels and gauntlet-type gloves should be provided for application of powder, should this prove necessary.

The storage and handling area should be clearly posted with signs warning that conventional fire extinguishing agents (foam, CO₂ and water) shall not be used on alkali fires.

A supply of mineral oil should be maintained in all handling areas. This is for use in the event a fire should occur and personnel inadvertently come in contact with an alkali metal; the affected area should be washed immediately with mineral oil.

F. TOXICITY OF MATERIALS

All of the alkali are reactive with moisture. The reactivity increases with temperature and is greatest when the metal is in a liquid state. Cesium, which is liquid at normal ambient temperature, will ignite spontaneously on contact with air. It is for this reason that storage at low temperature is generally recommended. However, because the alkali metals are doubly encapsulated in polypropylene and lead, and because corrosion tests show no effect of cesium on polypropylene at the test temperature (65°C), the storage and prelaunch temperature (40°F) was determined to be safe.

The toxic effects for all alkali metals to be used are primarily manifested in corrosive attack of body tissues. The oxide fumes are equally damaging if inhaled; therefore, personnel involved in control of an alkali fire should wear full body protection and a breathing apparatus closed to ambient air.

APPENDIX B

BLOCK DIAGRAMS OF EQUIPMENT FOR PRIMARY AND
TELEMETRY AIRCRAFT AND AT ASCENSION ISLAND

Aircraft Optical Equipment (AFSWC manned except as noted)

Ground Site--Ascension Island (Station 12) (AFSWC manned)
Optical Equipment

Ground Site--Ascension Island (Station 12) (AMR manned)
Optical Equipment

In addition to the above equipment, ARGMA-DAMP Ship and AFBMD-AVCO DC6 aircraft optical equipment will be viewing the AEC tests.

Atlantic Missile Range telemetry and ARGMA Nike-Zeus radar equipment will also cover the re-entry experiment.