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SNAP PROGRAMS
UPPER ATMOSPHERE
EXPERIMENTAL RE-ENTRY STUDY

Summary Report

July 1962

MND-P-2833

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FOREWORD

This topical report, under Contract AT(30-3)-217, Task 7--Radio-logical Safety Studies for Space Power, has been prepared by Martin Company, Nuclear Division. In compliance with requirements of the contract, this report, together with the two volumes of "Upper Atmosphere Re-entry Study--High Altitude Burnup" (Ref. 1), forms the final report of Task 7.

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Experimental test pod

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SUMMARY

In compliance with the requirements of Contract AT(30-3)-217, Task 7, Radiological Safety Studies for Space Power, this report is submitted as the last volume of the final report.

The principal objective of the two earlier volumes (Ref. 1) was to evaluate theoretical methods of determining the fate of radioactive fuels on re-entry into the earth's atmosphere and to recommend an experimental program to determine:

- (1) Size distribution of particulate matter resulting from burnup of fuel.
- (2) Fuel dispersion, residence time, and area of deposition.

This report describes the theory, design, and results of the SNAP Upper Atmosphere Experimental Re-entry Program. The principal objective of this study was to verify and/or improve the analytical techniques used in predicting the heating effects of orbital re-entry on radioisotope-fueled generators and their components.

The experimental program consisted of three phases:

- (1) Fuel Core Heating.
- (2) Fuel Core Ablation.
- (3) Generator Burnup.

The fulfillment of the objectives of the program was dependent upon the success of the ballistic flights of Atlas missiles. Flight requirements were completed for the Phase I experiments. Phase II experiments were not successful because of failure of the experiment-carrying Atlas missiles. The Phase III experiments were not assigned to a carrier and were therefore limited to design development.

Preflight analysis of the Atlas vehicle was performed to determine the possible trajectories of the test articles on re-entry. Standard and lofted R&D trajectories of the Atlas vehicle were considered. The equations of motion were coupled with the equation of re-entry heating to predict the altitudes, latitudes and longitude of test specimen burn-through (see Fig. 9).

Postflight analysis was dependent upon photographic, photometric, radar, telemetric and meteorological data. Powered flight radar data of successful flights was programmed into IBM 7090 codes to produce

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trajectories and heating rates as a function of time. The aerodynamic heat flux as a function of time was then used as an input to the IBM 7090 heat transfer code to determine the temperature gradient through the body and rate of ablation of the body. Times of test specimen ablation were related to trajectory time, and the corresponding altitudes of first lead ablation and specimen penetration were determined. Photographic and photometric data, when reduced, furnished altitudes of observed test specimen burnup. The predicted altitudes and observed altitudes were compared.

The radar systems gave excellent data while photographic, photometric and telemetric systems produced only partial information. Recommendations have been made to improve the acquisition of photographic and telemetric data for future flights.

Because of insufficient data, only tentative conclusions on the mode of test specimen re-entry, altitude of burnup and accuracy of the analytical procedures were possible. On Test 3751 first sodium light from the spherical specimens (Fig. 2a) was spectrally identified at 240,000 feet. Computed data for the trajectory flown on this test showed that a stable sphere would be penetrated and show sodium light at 240,000 feet. This close correlation of test and computed data tends to show the following significant conclusions:

- (1) That the sphere was stable upon re-entry.
- (2) That the computational techniques used in re-entry heating analysis are quite accurate.
- (3) That the design practice applied to SNAP flight hardware is conservative (i. e., design for burnup under heating occasioned by a tumbling and spinning re-entry ensures that burnup will occur).
- (4) That the test program was well conceived and did produce limited but significant results. Improvements in data collection and reduction can permit full realization of test objectives; these improvements were incorporated in the test conducted on August 31, 1962.

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I. INTRODUCTION

Radioactive fuel materials are an essential source of auxiliary power for use in space. The safety criteria established for the design of devices utilizing nuclear power determine their acceptability as power sources. The studies here reported were expected to verify or improve procedures employed in defining safety criteria as they pertain to aerodynamic heating effects upon radioisotope-fueled thermoelectric generators and their components.

This volume gives a brief description of the theory behind the upper atmosphere studies and the design of the studies, concentrating primarily on the evaluation of data from the experiments. Preflight analysis of the theory and design of the studies is provided in Ref. 2.

The principal objective of this study was to verify and/or improve the analytical techniques used in predicting the heating effects of orbital re-entry on radioisotope-fueled generators and their components. The study program was divided into three phases:

Phase I: Fuel Core Heating

Phase II: Fuel Core Ablation

Phase III: Generator Burnup

At this time, experimental data has been obtained only from the Phase I testing. Failure of test carriers (Atlas vehicles) for the Phase II experiment has precluded the possibility of securing test data. The Phase III program was restricted to the design of a mockup generator test specimen. Because of the unavailability of test carriers (Atlas missiles), testing was not possible. Phase I testing was intended to evaluate and/or improve analytical procedures for predicting re-entry heating effects on generator fuel elements of four different aerodynamic shapes. Phase II testing was intended to evaluate and/or improve analytical procedures used in predicting the ablation rate of generator fuel elements. Phase III testing was planned to check and/or improve the analytical procedures used in predicting re-entry heating effects on a heterogeneous package.

In sequence, the chapters which follow discuss

- (1) Pretest analysis and design and manufacture of hardware.
- (2) Conducting of the test and collecting data.
- (3) Analysis of test results.
- (4) Conclusions drawn with respect to program objectives.

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II. PREFLIGHT ANALYSIS--TEST SPECIMEN DESIGN AND MANUFACTURE

The Phase I test specimens comprised four different aerodynamic configurations (Fig. 2c) to show the effect of varying shape and ballistic coefficient on aerodynamic heating. Eight specimens of each configuration were used for a statistical study of the results.

The Phase II test was to provide information concerning ablation rates of re-entry bodies subjected to aerodynamic heating. Twenty-eight test specimens of identical external dimensions (Fig. 2d) but four different wall thicknesses (seven specimens of each thickness) were used, so that the burnthrough positions would be distributed with respect to altitude, thus providing a better indication of ablation rates experienced. Both Phase I and Phase II tests were scheduled to be run twice to determine the reproducibility of the results.

On each of the scheduled tests, a telemetry canister was assigned. It was designed to be similar in configuration and ballistic coefficient ($W/C_D A$) to other test specimens. Thermistors were included to sense temperatures at 26 points on the canister surface, and, throughout the re-entry heating phase, to transmit this information to receiving stations.

Phase I and Phase II test articles were assembled separately within their assigned scientific passenger pods (SPP). Each of the four pods was attached to a different Atlas missile (Fig. 1).

The SPP was separated from the Atlas vehicle at a velocity of approximately 5.5 fps, approximately 9 seconds after the Atlas vernier engine cutoff (VECO). It was designed to be ejected down and to the right at an angle of approximately 45° with the nose cone trajectory. At 3.75 minutes before the SPP was scheduled to descend to 400,000 feet altitude, test specimens were ejected from the pod. All specimens of a specific configuration were devised to be ejected simultaneously; ejections of different configuration occurred at 25-second intervals. The telemetry canister was ejected 2 seconds after the final test specimen.

Alkali metals were encapsulated in the test specimens to give off brilliant flashes of light upon burnthrough of test specimens. Configurations were identified through the use of a particular alkali metal, giving off light of a particular frequency, in each of the four configurations; filtered cameras and spectrometers therefore recorded flashes of a specific wave length for each specific specimen shape and wall thickness. The re-entry trajectory was triangulated with camera equipment located on two C-54 aircraft and on land sites on Ascension Island.

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Fig. 1. Pods on Atlas Missile

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Photographic data obtained by Air Force personnel and telemetry data recorded at Air Division was assigned to AFSWC for reduction.

A. DESIGN

1. Phase I and Phase II Test Specimens

Phase I test specimens comprised 8 spheres and 24 cylinders. The spheres were sodium-filled. The cylinders were divided into three groups of eight, each group having a different length-to-diameter ratio and each containing a different alkali metal (cesium, rubidium or potassium). Figure 2a shows the sodium-filled spheres; Fig. 2b, the cesium-filled cylinders. Details of test specimen design are shown in Figs. 2c and 2d.

All Phase II specimens were cylinders--seven each of four different wall thicknesses. The Phase I and Phase II test specimens were fabricated from lead-silver alloy (Pb + 0.1% Ag). Since liquid alkali metals corrode this alloy, the alkali metals (except sodium, which has a high melting point) were encapsulated in polypropylene containers prior to insertion into the test specimens. Table 1 illustrates the physical characteristics of test specimens.

2. Telemetry Canister

The telemetry canister was instrumented to measure, record and transmit canister wall temperature during re-entry. It was fabricated as a hollow cylinder, made from titanium alloy (5% Al, 2.5% Sn), 9.5 inches in diameter, 19.5 inches in length, and 0.292 inch in wall thickness. Re-entry temperature was to be measured by 23 thermistors distributed on the exterior surface of the cylinder. Three thermistors were mounted on the inside wall to measure temperature and thus permit determination of the thermal gradient in the wall. Within the titanium shell, insulation provided thermal protection for the electronic systems. A fiberglass cylinder 1/8 inch in thickness was fitted to the inside diameter of the insulation to provide annular support and alignment for the electronic components. Preformed Min-K insulation pads 1 inch thick, backed by titanium alloy retainer plates, closed both ends of the cylinder. Transmitter antennae were attached to each retainer plate. The antennae were protected from the re-entry heat pulse by ceramic domes held in place by a titanium alloy retainer ring threaded into the cylinder. Thermal shock to the ceramic domes was prevented by a 100-mil coating of AVCOAT II*, an ablative material.

The internal electronic and electrical systems of the canister included a battery power supply, voltage oscillators, power amplifiers,

*AVCO Rod Corporation.

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Fig. 2a. Group 1, Phase I, Spherical Capsules--Sodium Fill

Fig. 2b. Group 2, Phase I, Cylindrical Capsules--Cesium Fill

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Group 1

Group 2

Group 3

Group 4

NOTE:
All dimensions in inches.

Fig. 2c. Re-entry Capsules SNAP Hazards Tests, Phase I

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Fig. 2d. Re-entry Capsules SNAP Hazards Tests, Phase II

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TABLE 1
Physical Characteristics of Test Specimens*

Phase No.	Group No.	No. per Flight	Dimensions (diameter x length)	Wall Thickness	Total Weight (per specimen)	Aerodynamic Ballistic Coefficient (W/C _D ^A)	Alkali	Alkali Weight	Total Weight, 8 Capsules
I	1	8	Sphere, 3 D	3/8	3.51	77.5	Na	0.163	28.08
	2	8	Cylinder, 2 D x 5 L	3/8	4.60	86.0	Cs	0.153	36.80
	3	8	Cylinder, 2-1/2 D x 5 L	3/8	6.37	77.7	Rb	0.303	50.96
	4	8	Cylinder, 3 D x 4-1/2 L	3/8	7.38	83.5	K	0.267	59.12
									174.96
									Total Weight, 7 Capsules
II	1	7	Cylinder, 2-1/2 D x 5 L	1/4	4.70	57.3	Na	0.442	32.90
	2	7	Cylinder, 2-1/2 D x 5 L	3/8	6.15	75.0	K	0.174	43.40
	3	7	Cylinder, 2-1/2 D x 5 L	1/2	7.50	91.5	Rb	0.207	52.50
	4	7	Cylinder, 2-1/2 D x 5 L	5/8	8.46	103.0	Cs	0.144	59.50
									188.30

*All dimensions in inches and weights in pounds.

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a commutator, a magnetic tape recorder and reproducer, and a transmitter. This equipment was to be energized by an electrical signal just prior to re-entry. A programmer housed in the scientific passenger pod was the signal source. All the sensed temperatures were to be transmitted twice to the receiving station, the first transmission occurring the instant the temperature was sensed, and the second transmission occurring after a 30-second delay to be effected through the use of a recorder/reproducer. This system was planned to prevent loss of data as a result of transmission blackout, which occurs when an ion sheath is generated in the atmosphere by a re-entry body. The ion sheath persists for approximately 20 seconds along the trajectory used for this test program. The transmission frequency is 244.3 megacycles.

The telemetry canister weighs approximately 85 pounds, 40 pounds of which comprises the shell, insulation and end plates. Its ballistic coefficient ($W/C_D A$) is 70.3.

Figures 3a and 3b show the instrumented canister shell. A schematic drawing, Fig. 4, illustrates canister construction. Figure 5 is a schematic of the telemetry canister electrical system.

3. Phase III

Two different test specimen designs were developed, but neither was built. Model A, Fig. 6, was designed for burnup on a ballistic trajectory similar to that planned for Phase I and Phase II testing. Sodium was to simulate the fuel core of the generator. Model B, Fig. 6, was designed for burnup on a simulated orbital re-entry (simulated by a powered re-entry of a vehicle such as the Pershing or Scout). The flare material was to be encased in Haynes-25 alloy, a material used for fuel encapsulation in operational SNAP generators. The use of this material was the principal reason for the requirement of the higher integrated heating of the powered re-entry.

4. Ejection Mechanism

The test specimen ejection mechanism, Fig. 7, consisted of five eject cylinders and associated hardware. Five units were built and incorporated within the structure of the scientific passenger pods. Four of the eject cylinders contained the four groups of test specimens; the fifth eject cylinder contained the telemetry canister. Lock pins retained the test articles under spring tension within the eject cylinders. At predetermined times, electrical signals from the pod programmer ignited the squibs which actuated the solenoids. The solenoids retracted the lock pins, thus allowing ejection of the test specimens and telemetry canister. The velocity of ejection was designed to be 4 ± 2 fps.

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View a

View b

Fig. 3. Telemetry Capsule Showing Transducers and Insulation

Fig. 4. Re-entry Telemetry Capsule (500-lb pod)

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Fig. 5. Telemetry Canister Electrical System

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Fig. 6. Phase III Specimens

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Fig. 7. Capsule Ejection Mechanism End View

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In Fig. 8, the sequence of loading the test specimens within the ejection mechanism is shown. The arrangement of the lead capsules in the ejection cartridge is illustrated in Fig. 8a. Figures 8b and 8c show the loading of the specimens within the cylinder; Fig. 8d, the loading of the telemetry canister.

B. METHODS OF ANALYSIS

Evaluation of the re-entry behavior and ultimate fate of a body required the simultaneous solution of trajectory, aerodynamic heating and heat transfer equations.* A detailed description of methods used is presented in appendices of Ref. 2. Aerodynamic heating is primarily a function of the altitude, velocity and shape of the body, parameters which also determine the re-entry trajectory. The equations of heating and equations of motion were programmed for the IBM 7090 to produce printouts of the trajectory and heating rate as a function of time. The aerodynamic heat flux as a function of time was then used as an input to the IBM 7090 heat transfer code to determine the temperature gradient through the body and the rate of ablation of the body.

During re-entry, ablation significantly alters aerodynamic parameters such as ballistic coefficient. To account for this effect, an iterative routine is followed by the IBM 7090. Flight parameters are computed and ablation is calculated until a point is reached where the body change is significant. New flight parameters and heat flux data are then computed for the partially ablated body and used as new inputs to the trajectory and heat transfer codes. The procedure is continued until the body is completely ablated or until it impacts at the end of its trajectory. All lead test capsules are predicted to be completely ablated. Table 2 gives the minimum and maximum predicted altitudes of burnup for each test specimen of Phases I and II. The minimum altitude is obtained if the re-entering body both tumbles and spins; the maximum altitude results if spinning alone is assumed. Since the heat flux depends on the trajectory, and since the exact trajectory to be achieved in actual test cannot be predetermined, the burnup altitudes (maximum and minimum) were calculated for re-entry flight path angles from -16.3 to -27 degrees. This range was selected because the Atlas vehicle will fly either a lofted (-24 degrees) or standard (-19.3 degrees) trajectory. A deviation of ± 3 degrees is associated with each of these R&D mission trajectories (see Fig. 10).

The theoretically predicted temperatures at several significant points on the telemetry capsule are shown in Fig. 11. For the analysis, the cylindrical capsule was assumed to be tumbling and spinning during a lofted mission. The temperature profiles were determined by applying the heating rate of a lofted trajectory to a two-dimensional model in the digital heat transfer code. During the maximum heating

*See Fig. 9, a block diagram showing sequence of data collection and reduction used in preflight analysis.

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Fig. 8a. SNAP Re-entry Test Assembled at Fuel Storage Area

Fig. 8b. Installation of Flare Capsules into Pod

Fig. 8c. Installation of Flare Capsules into Pod

Fig. 8d. Installation of Canister in Pod

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TABLE 2
Predicted Altitudes of Test Specimen Burnup

Test Phase	Weight (lb)	Drag Coefficient, $W/C_D A$	Dimensions (in.)	Alkali	Re-entry Angle (deg)	Burnup Altitude (ft x 10 ⁵)	
						Minimum	Maximum
I	3.51	77.5	Sphere 3, dia 3/8, wall	Na	-16.3	2.09	2.09
					-19.3	2.02	2.02
					-22	1.98	1.98
					-24	1.92	1.92
					-27	1.87	1.87
I	4.6	86.0	Cylinder 2, dia 5, length 3/8, wall	Cs	-16.3	1.88	2.04
					-19.3	1.80	1.98
					-22	1.73	1.89
					-24	1.71	1.88
					-27	1.67	1.85
I	6.37	77.7	Cylinder 2.5, dia 5, length 3/8, wall	Rb	-16.3	1.78	1.99
					-19.3	1.75	1.93
					-22	1.71	1.88
					-24	1.65	1.85
					-27	1.59	1.76
I	7.38	83.5	Cylinder 3, dia 4.5, length 3/8, wall	K	-16.3	1.72	1.99
					-19.3	1.64	1.39
					-22	1.58	1.84
					-24	1.55	1.79
					-27	1.50	1.65
II	4.7	57.3	Cylinder 2.5, dia 5, length 1/4, wall	Na	-16.3	1.72	1.88
					-19.3	1.66	1.83
					-22	1.59	1.77
					-24	1.54	1.71
					-27	1.49	1.66
II	6.15	75.0	Cylinder 2.5, dia 5, length 3/8, wall	K	-16.3	1.78	1.99
					-19.3	1.75	1.93
					-22	1.71	1.88
					-24	1.65	1.85
					-27	1.59	1.76
II	7.5	91.5	Cylinder 2.5, dia 5, length 1/2, wall	Rb	-16.3	1.69	1.85
					-19.3	1.63	1.80
					-22	1.57	1.74
					-24	1.50	1.69
					-27	1.47	1.64
II	8.46	103.0	Cylinder 2.5, dia 5, length 5/8, wall	Cs	-16.3	1.60	1.75
					-19.3	1.50	1.69
					-22	1.45	1.65
					-24	1.39	1.58
					-27	1.35	1.55

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Fig. 9. Preflight Analysis--Upper Atmosphere Experimental Re-entry Study

Fig. 10. Stagnation Heating Rates--Three-Inch Diameter Sphere, Phase I Testing

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Fig. 11. Expected Temperature Profile--Telemetry Capsule

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period, the temperature at the telemetry capsule corner (B of Fig. 11) exceeded that on the surface of the capsule (A of Fig. 11) by approximately 600° F. The canister was predicted to re-enter intact with minor yield in the vicinity of B of Fig. 11.

C. DATA ACQUISITION AND REDUCTION

Geophysics Corporation of America, under subcontract to Martin Company, aided in the selection of the photographic and photometric equipment to be used for data acquisition.

1. Photographic Data

The tests were to be observed from aircraft provided by both AFSWC and AMR, from Ascension Island, and from the American Mariner, an instrumentation ship. Camera equipment was to include K-24 aerial cameras, BC-4 star camera, 16- and 35-mm cinecameras, and a Hulcher 70-mm sequence spectrometer. Exposed spectrometer and filtered K-24 camera films were to be used to differentiate between test specimens on the basis of the characteristic wave lengths of light emitted by the several alkali materials. Unfiltered K-24 cameras were to record re-entry events along with a star background for precise triangulation of the events. The BC-4 camera was to be open throughout the re-entry, recording the streaking of burning bodies. A chopper, applied to obscure the aperture approximately four times per second, was to cause breaks in the streaks recorded on the film plate. From the knowledge of time, streak length and camera orientation confirmed by star background, test specimen re-entry velocity was to be determined.

2. Photometric Data

One two-barrel photometer was to be hand-trained on the re-entry events. The photometer was timed-indexed to a visicorder to record a real time history of relative light intensities existing during re-entry burnup of test specimens. One barrel of the photometer was to be filtered for preferential observation of light of $7800 \pm 50\text{\AA}$, the principal rubidium line; the other barrel, for light of $8521 \pm 50\text{\AA}$, the principal cesium line. On penetration of the rubidium- and cesium-filled test specimens, light of the appropriate wave lengths would peak in intensity. Obtained time values were to be correlated with re-entry radar data to determine burnup altitude. Data obtained in this manner was to serve as an independent check of altitudes determined by camera triangulation techniques. The Barnes Engineering Corporation, under contract to AFSWC, was to provide and operate both the photometer and Hulcher 70-mm spectrometer.

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3. Radar Data

The Atlantic Missile Range was to provide two types of radar support from Ascension Island: re-entry trajectory data and aircraft positioning. Nose cone trajectory data was to be obtained from a beacon tracking radar. Since the nose cone will appear on time-marked photographic plates with the test specimens, burnup altitude can be deduced from nose cone time-position history as revealed by radar. The Mod II and Nike-Hercules radars at Ascension Island were to be used to vector the observation aircraft to prescribed positions and courses for viewing the re-entry. It was essential that the aircraft be on course at the precise position and time that re-entry occurred since most of the cameras recording test events are fixed-mount equipment. The radar track of the aircraft positions was to be permanently recorded during the re-entry, so as to be used, with triangulation, to determine the spatial coordinates of test specimen burnup.

4. Telemetry Data

The output frequency of the telemetry canister transmitter is 244.3 megacycles. In the event of test shot failure, additional information telemetered at 256.1 mc from the scientific passenger pod was to be of value in troubleshooting. Information telemetered at 256.1 mc included a signal of positive pod separation from the Atlas vehicle and a signal of positive ejection of each group of test specimens and telemetry canister from the pod.

AMR telemetry receiving stations at Cape Canaveral, Antiqua, Grand Bahama and Ascension Islands were to receive the transmitted frequencies and record them on magnetic tape (AMPEX FR-100). Copies of the tapes were to be furnished to AFSWC for data reduction. Data was to be reduced in accordance with the work flow diagram of Fig. 12.

5. Meteorological Data

Aerodynamic heat flux determination requires that the density of the atmosphere be considered. The ARDC standard atmosphere model has been assumed in predicting re-entry burnup altitudes. At the time of Phase I and Phase II tests, the AMR is to determine actual atmospheric conditions in the re-entry test area to an altitude of 110,000 feet. For postflight analysis, atmospheric conditions above a 110,000-foot altitude were to be assumed to be those of the ARDC 1959 Standard Atmosphere Model.

Fig. 12. Telemetry Data Reduction

III. RE-ENTRY TESTING AND DATA COLLECTION

A. PHASE I

1. Flight Test No. 3751

The two Atlas missiles assigned to Phase I achieved successful flights. The first of the two flights (AMR Test No. 3751) was launched from Complex 11 on Atlas Missile 4F at 2104/11 Greenwich Civil Time (Zulu Time) on November 22, 1961, at the Air Force Missile Test Center, Florida. From radar and optical data obtained at the launching site and at the downrange stations, it is concluded that Missile 4F flew a near-nominal trajectory of a lofted R&D mission (Ref. 5). All the trajectory events--main engine cutoff (MECO), sustainer engine cutoff (SECO), vernier engine cutoff (VECO), pod ejection--occurred in the proper sequence. The re-entry of the vehicle tankage, nose cone and the SNAP test specimens were observed optically and visually. Test data from the telemetry test specimen was not received. Based on the General Dynamics Astronautics nominal trajectory data for a lofted R&D mission, the SNAP specimens were predicted to be located below the vehicle tankage at the time of re-entry. Their actual position on re-entry was above the tankage but below the nose cone. Figures 13 and 14 illustrate the re-entry of Test 3751. The incorrect location of the SNAP experiment within the re-entry complex is credited to the improper orientation of the SNAP experiment with respect to the missile flight path at the time of ejection. This improper orientation was probably caused by the rotation of the Atlas missile about its longitudinal axis (Ref. 7).

2. Flight Test No. 5462

The second flight of the SNAP experiment (AMR Test No. 5462) was launched from Complex 11 on Atlas Missile 35E at 2040/05 Greenwich Civil Time (Zulu Time) on December 1, 1961, at the Air Force Missile Test Center, Florida. As in the first experimental flight (Missile 4F), radar and optical data established that Missile 35E flew a near-nominal trajectory of a lofted R&D mission (Ref. 6). The re-entry complex, consisting of the vehicle tankage, nose cone, and the SNAP test specimens, was observed optically and visually. As in the first flight (3751), data from the telemetry test specimen was not obtained. Downrange optical data confirmed the theoretically predicted position of the SNAP experiments relative to the vehicle tankage and nose cone. Figure 12 illustrates the re-entry phase of Test 5462 and shows the SNAP experiment below the vehicle tankage, as predicted.

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Fig. 13. Re-Entry Complex of Test 3751 -- Ascension Island Ballistic Camera

Fig. 14. Re-Entry Complex of Test 3751 -- Airborne Ballistic Camera

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B. PHASE II

The SNAP experiments for Phase II of the test program were carried by Atlas Missiles 5F and 6F. The first launching occurred on December 9, 1961. Premature sustainer engine cutoff of the 5F missile resulted in failure of the flight. No experimental data was obtained.

On December 22, 1961, the second Atlas missile (6F) was launched. However, the missile aborted during the ascent phase of flight. Again, no experimental data was acquired.

To acquire flight data from the Phase II experiments, an additional flight has been planned. The tentative launch date is July 31, 1962.

C. DATA ACQUISITION OF PHASE I

Test data was collected by

- (1) The Air Force Special Weapons Center.
- (2) The Air Force Ballistic System Division.
- (3) The Air Force Missile Test Center.

The data from the first flight test (Phase I, Test 3751) received by Martin Company prior to the time of this report are:

- (1) Ballistic camera terminal position data.
- (2) RCA/AMR flight test data, Data Reduction Report No. 72K, optical altitude data.
- (3) Radar data, FPS-16 radar.
- (4) Radar data, Mark II Azusa.
- (5) Preliminary draft, AFSWC test results.
- (6) Re-entry report, Barnes Engineering Company.
- (7) Miscellaneous films.

The data of the second flight test (Phase I Test No. 5462) received prior to the time of this report are:

- (1) Preliminary draft, AFSWC test results.

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- (2) Damp re-entry report.
- (3) Final data, Mark II Azusa radar.
- (4) RCA/AMR optical and radar data, FPS-16.
- (5) Miscellaneous films.

1. Powered Flight

Acquisition of data for the powered flight portion of the Atlas missile trajectories was obtained by means of optical equipment, pulse radar and continuous-wave radar, which compose part of the AFMTC standard metric tracking system (see Fig. 15).

a. Standard optical metric system

The Mitchell motion picture camera was used at the launch site to photographically record the launching of Atlas Missiles 4F and 35E.

The Askania Kth 53 theodolite instrument was used at the launch site. The theodolite system covered the trajectory of the missiles from launch to 100,000 feet, providing secondary coverage for the standard fixed metric camera system from 0 to 2000 feet. Photographic conditions permitting, the theodolite is the primary source of position and velocity data from 2000 to 100,000 feet.

The standard fixed metric camera systems used were the CZR-1 and RC-5. These instruments are ribbon frame cameras placed on trailers or permanently mounted towers. Each individual camera gives the direction of a light ray in space from the camera to the missile. A minimum of two cameras must be used to obtain ray intersections and, therefore, the missile position. Typical coverage for position data is from 0 to 2000 feet.

b. Pulse radar

The FPS-16 radar is specifically designed for missile tracking. The FPS-16 radar provided metric position data from launch through burnout for Tests 3751 and 5462. This data was presented in the AMR rectangular coordinate system (x, y, z). It consisted of distance, velocity and acceleration of the missiles. This radar data was transformed by Martin Company from the AMR rectangular coordinate system to the geodetic coordinate system (latitude, longitude and altitude) at locations of interest in the trajectories. Actual flight parameters (latitude, longitude, altitude and velocity) at the particular locations (SECO, VECO and pod ejection) were used as inputs into the Martin IBM 3-D Trajectory Program. Program trajectories representative of the actual were reproduced for later use in data evaluation.

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Fig. 15. Data Acquisition System--Upper Atmosphere Experimental Re-entry Study

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c. Continuous-wave radar

The Azusa Mark II determines successive trajectory positions of a transponder within the missile by continuous comparison of phase differences between microwave signals transmitted to, and received from, the airborne transponder. Like FPS-16 radar data, Azusa Mark II data was presented in the AMR rectangular coordinate system and transformed into geodetic coordinates before application in the 3-D program. Comparisons of trajectories determined by the Azusa II and FPS-16 radars revealed negligible difference. Since the accuracy of the Azusa II system was considered greater than that of the FPS-16 system, trajectories determined from Azusa II data were used in analysis of test results.

2. Terminal Flight

Terminal flight data consisted of FPS-16 radar data and photogrammetric data on Test 5462 and photogrammetric data only on Test 3751 (see Fig. 15). Photogrammetric equipment included a spectrometer, a photometer, cinecameras, ballistic cameras and K-24 (filtered and unfiltered) cameras. Locations of aircraft which carried photogrammetric equipment are shown in Fig. 16 (also Figs. B-7 and B-8, Ref. 2).

a. Flight Test 3751

(1) Ballistic camera data

Ballistic cameras were located on Ascension Island and on the aircraft operated by AFSWC. These cameras provided locations of the vehicle tankage, nose cone and flare capsules at the re-entry (Ref. 8). Identification of a given flare group was not possible, but the entire range over which the flares give visual indication of burning was available. Visible flare trace coordinates, as determined by the ballistic cameras, are given in Tables 3 and 4. AFSWC did not determine velocity of specimens at burnup; ballistic camera data was to have been used for this purpose.

TABLE 3

Visible Flare Trace Coordinates

<u>Flare</u>	<u>Latitude (degrees)</u>	<u>Longitude (degrees)</u>	<u>Altitude (feet)</u>
Beginning	-7.388	-15.837	224, 276
End	-7.498	-15.663	188, 591
Beginning	-7.282	-16.006	265, 390
End	-7.634	-15.447	136, 235
Beginning	-7.387	-15.839	222, 514
End	-7.503	-15.655	184, 087

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Fig. 16. Locations of Data Acquisition Stations

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The standard deviation for the calculated altitude of the flare ignition is 1400 feet.

TABLE 4
Visible Flare Trace Coordinates

<u>Flare</u>	<u>Latitude (degrees)</u>	<u>Longitude (degrees)</u>	<u>Altitude (feet)</u>
Beginning of 1st lead flare	-7.352	-15.895	240,039
Ending of 1st lead flare	-7.445	-15.748	208,841
Beginning of 2nd lead flare	-7.355	-15.889	239,020
Ending of 2nd lead flare	-7.476	-15.698	197,842
Beginning of 3rd lead flare	-7.388	-15.838	227,841
Ending of 3rd lead flare	-7.487	-15.680	194,123
Beginning of lead and so- dium trace	-7.352	-15.895	240,039
Ending of lead and sodium trace	-7.470	-15.708	200,024

(2) Spectral analyses-cinespectrometer and photometer

The cinespectrometer and photometer were operated by Barnes Engineering Company from the aircraft operated by the Air Force Missile Test Center.

The cinespectrometer provided a film record from which the chemical composition of observed materials at re-entry was to be determined. The instrument was designed for observation of the spectral region containing all of the flare materials. The lead flare capsules were observed on the film and, except for sodium, the spectral emission of the alkali materials was not observed. Data from the cinespectrometer is shown in Table 4.

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The photometer was used to observe the flashes of light of the wave length and intensity expected to be emitted at the time of flare ignition. This photometer was mounted in the AMR-operated aircraft. Because of the difference between the predicted and actual locations of the flares with respect to the Atlas re-entry complex, the photometer (two-degree field of view) was unable to obtain the desired data.

(3) Motion pictures

Two 35-mm cameras mounted in the AFSWC aircraft were loaded with black and white film and operated at 32 frames per second. A 16-mm camera was located on the same aircraft. This camera was loaded with color film and operated at 24 frames per second. A fourth camera, a 16-mm, was located at Ascension Island. This camera was loaded with black and white film and operated at 24 frames per second. A fifth camera, a 16-mm also located at Ascension Island, was operated at 100 frames per second.

Data was obtained from only one of the two 35-mm cameras. Images of SNAP specimens, the Atlas nose cone and tankage were definitely displayed on the film. However, data recorded was of limited usefulness because of the loss of the timing sequence during re-entry. To establish the film time, a comparison with other test data was necessary. The quality of reduced data obtained in this manner is dubious.

(4) K-24 cameras

Six K-24 cameras were operated from the AFSWC aircraft, and six were operated at Ascension Island. At each location, four cameras operated at 2-1/2 frames per second and two cameras operated at 1/2 frame per second. The four cameras operating at 2-1/2 frames per second were to discriminate spectrally, by the use of gelatin filters, among the various elements in the test specimens. The other cameras, operating at 1/2 frame per second were to give the directions of the flare packages by photographing the flares against a star background.

Results achieved from the K-24 cameras were unsatisfactory. Of twelve K-24 cameras, four malfunctioned because of film feed and focusing difficulties. The films from the other cameras were reviewed by the Instrument Company of Florida (ICF). Both ICF and AFSWC concluded that the photogrammetric data received was of poor quality.

b. Flight Test 5462

(1) Ballistic camera

The ballistic camera plate of Test 5462 is shown in Fig. 17. On this plate three definite traces, in addition to the Atlas tankage and nose cone, are observable. It is assumed that the uppermost trace

Fig. 17. Re-Entry Complex of Test 5462 -- Airborne Ballistic Camera

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and the lower trace are flare groups. The middle trace was not identified. The following altitude data was calculated, with the assumption that all traces are located in the same vertical plane as the Atlas re-entry vehicle.

<u>Trace</u>		<u>Latitude (degrees)</u>	<u>Longitude (degrees)</u>	<u>Altitude (feet)</u>
Upper VII	Begins	7.404	15.785	210,400
	Ends	7.539	15.579	168,100
Middle III	Begins	7.366	15.843	209,800
	Ends	7.452	15.711	184,000
Lower IV	Begins	7.322	15.910	220,500
	Ends	7.470	15.684	175,500

(2) Spectral analyses--cinespectrometer and photometer

The cinespectrometer data indicated that four lead traces had been observed. The altitudes of flare capsule visibility, allowing for the actual trajectory plane are:

<u>Trace</u>	<u>Altitude of Appearance (feet)</u>	<u>Altitude of Disappearance (feet)</u>
I	232,000	150,700
VII	218,300	160,900
IV	222,400	168,000

Identification of the contained alkali materials was not achieved.

The test specimens were located close to the Atlas tankage during re-entry. Because the tankage burned with extreme brilliance, the photometer was saturated and hence failed to provide data concerning the ignition of the test specimens.

(3) Motion pictures

Several cinecamera films were obtained from the flight. Three 16-mm films taken by AVCO Everett from the aircraft were available, together with films from the AMR IGOR camera at Ascension Island. Since a timing error may have been introduced during initial correlation of AFSWC photographs with these films, the AVCO and IGOR films will be separately reduced and the results submitted in a final report by AFSWC.

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(4) K-24 camera

As in the first experimental flight test, data obtained by the K-24 cameras was unsatisfactory.

c. Discussion

Because of the unsatisfactory performance of the K-24 cameras, it was deemed necessary to perform a study evaluating the cameras and their operation. From this study, the following causes for poor performance were discovered:

- (1) Films overexposed.
- (2) Many cameras out of focus.
- (3) Many cameras indicated.
 - (a) Pressure heat markings on film.
 - (b) Unevenly spaced fiducials.
 - (c) Image streaking (film moved before the lens closed).
- (4) Ground cameras jiggled because they were mounted.
- (5) A number of cameras had light leaks.
- (6) The fiducial systems were inadequate, both in number and quality.
- (7) Several lenses had pronounced coma.

d. Recommendations

It is recommended that the shutter curtains be installed in accordance with the manufacturers' recommendations.

Storage facilities should be provided aboard the AFSWC aircraft so that the films can be transported to and from Ascension Island in conformity with the film manufacturers' recommendations.

Legible identification of film should be made.

Cameras should be focused, repaired, star-calibrated and shutter operation timed.

These and additional changes in data-collecting techniques have been incorporated in the Phase II test scheduled for July 31, 1962.

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IV. DATA EVALUATION

A. POSTFLIGHT ANALYSIS--TRAJECTORY

The Radio Corporation of America transformed raw radar data (azimuth, range, elevation) into Cartesian coordinates (linear displacement) referenced to the launch site. The Cartesian coordinates were transformed for analysis into geodetic coordinates (latitude, longitude, altitude) by Martin Company, using a digital computer program.

Each of the radar tracking systems for a given instrumentation (Azusa II and FPS-16) consisted of two different origins (Origins 2 and 3). Origin 2 was defined at the launcher, whereas Origin 3 was located at GMLF No. 1, Model III tracker. Azusa II and FPS-16 data were presented and referenced to each origin. For a given instrumentation (Azusa II or FPS-16), the comparison of similar data points indicated extremely small differences. These differences were attributed to deviation of the origins. Therefore, for the remainder of the analysis, error due to origin was assumed negligible.

A study of the extent of variation in burnup altitude caused by data differences between radars (Azusa II and FPS-16) was then undertaken. Data from each radar system was used to determine the actual flight trajectory to test specimen ejection. The actual test specimen trajectory was then computed to impact. Figures 18, 19, 20 and 21 show the significant sodium capsule re-entry parameters for Tests 3751 and 5462, with Azusa II and FPS-16 input conditions, respectively.

The comparison of actual flight data (Atlas Missiles 4F, 35E) at SECO and VECO to the predicted flight (nominal, fast and slow) is shown in Table 5. Actual flight position at these conditions was closest to the predicted nominal flight. Actual impact position, determined where possible, agrees with the theoretical impact point. With reference to re-entry, several interesting results were observed. They are shown in Table 6.

There was very little difference in the heating period and average re-entry flight path angle between radars. Differences noted are considered small and proved negligible in their cumulative effect on computed altitudes of burnup.

B. POSTFLIGHT ANALYSIS--HEATING

The Azusa II and FPS-16 trajectory heating rates were applied to the Group I (sodium sphere) test specimens to determine ablation behavior for the stable and spinning modes of re-entry. From this study,

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Fig. 18. Re-entry Parameters--Test 3751, Azusa Data, Sodium Capsule

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Fig. 19. Re-entry Parameters--Test 3751, FPS-16 Data, Sodium Capsule

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Fig. 20. Re-entry Parameters--Test 5462, Azusa Data, Sodium Capsule

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Fig. 21. Re-entry Parameters--Test 5462, FPS-16 Data, Sodium Capsule

TABLE 5
Comparison of Flight Trajectory Parameters

Stage of Trajectory	Parameters of Stages of Trajectory	Predicted Lofted Trajectory			Flight Test No. 3751 (4F)				Flight Test No. 5462 (35E)			
		Fast	Nominal	Slow	FPS-16-2	FPS-16-3	Azusa 2	Azusa 3	FPS-16-2	FPS-16-3	Azusa 2	Azusa 3
SECO	Time (sec)	268.02	291.89	311.86	289.46	289.46	289.46	289.46	291.2	291.2	291.2	291.2
	Velocity (fps)	20,180.2	20,155.8	20,212.2	20,139	20,139	20,132.3	20,132.3	20,048	20,048	20,024.8	20,024.8
	Altitude (ft)	1,094,021.5	1,056,750.2	993,103.8	1,070,602	1,070,583	1,071,414	1,071,422	1,016,888	1,016,916	1,017,274	1,017,287
	Longitude (deg)	74.8322	74.0627	73.3890	74.1550	74.1551	74.1565	74.1565	74.1138	74.1138	74.1140	74.1140
	Latitude (deg)	26.8358	26.5683	26.3242	26.5889	26.5890	26.5878	26.5878	26.5661	26.5662	26.5654	26.5654
VECO	Time	287.23	312.15	332.41	308	308	308	308	308.55	308.55	308.55	308.55
	Velocity	19,994.8	19,977.8	20,047.4	19,993	19,993	19,983.8	19,983.8	20,082	20,082	20,058.2	20,058.2
	Altitude	1,261,420	1,217,194	1,145,179	1,219,556	1,219,563	1,220,200	1,220,210	1,153,013	1,153,017	1,152,992	1,153,002
	Longitude	73.8832	73.0476	72.3428	73.2289	73.2289	73.2304	73.2304	73.2358	73.2358	73.2367	73.2367
	Latitude	26.5329	26.2331	25.9687	26.2832	26.2832	26.2826	26.2826	26.2750	26.2750	26.2754	26.2754
Pod separation	Time				318		318		318		318	
	Velocity				19,915.1		19,866.7		19,988.2		19,946	
	Altitude				1,298,480		1,299,076		1,225,722		1,225,663	
	Longitude				72.73652		72.73732		72.76398		72.76518	
	Latitude				26.11707		26.11642		26.11604		26.11606	
Re-entry (sodium sphere)	Heating period (sec)				60		60		55		55	
	Max q_s (Btu/ft ² -sec)				1221.3		1214.9		1196.5		1189.2	
	Total Q_s (Btu/ft ²)				15,817		15,742		15,948		15,892	
	Avg flight path angle (deg)				-25.5		-25.5		-25		-25	
	Burnup altitude (ft)											
	Spin				190,000		190,000		193,000		192,000	
	Stable				243,000		242,000		242,000		244,000	
Impact	Longitude (deg)		14.744				14.761*				14.777	
	Latitude (deg)		-8.075				-8.070*				-8.065	

*Estimated using 35E data.

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TABLE 6
Re-entry Parameters

<u>Parameter Difference</u>	<u>Test 3751</u>	<u>Test 5462</u>
Stagnation heating rate (q_s Azusa - q_s FPS-16) ^{max} (Btu/ft ² -sec)	-6.4	-7.3
Total stagnation heat (Q_s Azusa - Q_s FPS-16) (Btu/ft ² -sec)	-75	-56
Heating period (sec)	0	0
Average flight path angle (deg)	0	0

<u>Mode of Re-entry</u>	<u>Test 3751</u>	<u>Test 5462</u>
Rb cylinder, stable, parallel	233,000	234,000
Rb cylinder, stable, 45°	227,000	227,000
Rb cylinder, spin- ning, normal	183,000	187,000
Rb cylinder, spin- ning, 45°	173,000	177,000
Rb cylinder, spin- ning, tumbling	167,000	166,000
K cylinder, normal	230,000	231,000
K cylinder, parallel	226,000	222,000
K cylinder, stable, 45°	224,000	223,000
K cylinder, spin- ning, normal	181,000	177,000
K cylinder, spin- ning, 45°	171,000	168,000
K cylinder, spin- ning, tumbling	152,000	155,000

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altitudes of test specimen initial ablation and of flare release were obtained. The computed altitudes of penetration differed between radars by not more than 2000 feet. It was concluded that position and velocity differences between Azusa II and FPS-16 data resulted in a tolerable error in test specimen burnup altitude. Analysis of the cylindrical specimen heating was confined, therefore, to consideration of input data from the Azusa II alone.

Results of the structural heat transfer analysis are presented in Figs. 22 and 23. According to the analysis, when the lead element No. 4 ablates, the flare material is released. This represents the final layer of lead structure surrounding the flare material in the digital heating code. The sphere may be stable or spinning on re-entry. In the latter case, the average heating rate seen by each point on the sphere's surface is approximately 30% (Ref. 2) of the stagnation heating rate. Burnup (flare release) altitudes for the spinning and stable re-entering spheres were 190,000 and 242,000 feet, respectively, from Test 3751, and 192,000 and 244,000 feet, respectively, in Test 5462.

C. COMPARISON TO OBSERVED DATA

Optical data results of Test 3751 indicated that sodium from spherical test specimens was visible between 240,000 and 200,000 feet altitude. Burnup altitudes determined from the actual trajectories for stable and spinning spheres defined a limited altitude range (242,000 to 190,000 feet), as shown in Table 7. This shows excellent agreement with the band of optical burnup altitude data. Since release of flare material began at 240,000 feet, the sphere was assumed to have re-entered in the stable mode.

D. EXTENSION OF PREDICTED DATA

On the basis of the actual test trajectory heating rates, a heating analysis was performed to determine cesium, rubidium and potassium test specimen flare release altitudes for the following cylindrical test specimen orientations:

- (1) Stable, axis normal to flow.
- (2) Stable, axis parallel to flow.
- (3) Stable, axis 45° to flow.
- (4) Spinning, axis normal to flow.
- (5) Spinning, axis 45° to flow.
- (6) Spinning and tumbling.

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Fig. 22. Thermal History of Sodium-Filled Sphere--Test 3751, Azusa Data

Fig. 23. Thermal History of Sodium-Filled Sphere--Test 5462, Azusa Data

The evaluation program is presented in block diagram form in Fig. 24. The results are presented in the bar graphs of Figs. 25 and 26. On the graphs, an altitude range for the demise of the specimens, for the various re-entry orientations, is defined by the beginning of lead melting to the release of the alkali flare. Superimposed on these figures is the test data defining the beginning and ending of observed flare traces (lead and sodium, unidentified alkalis, lead only). The intent here was to deduce the re-entry orientation of the capsules without prior knowledge as to the flare material each contained. It had been intended that spectral data received from the tests would have identified the flares. However, such data was not acquired. Unfortunately, because of altitude overlap for the various flare orientations, the mode of re-entry could not be ascertained. To establish the mode of re-entry it is concluded that the alkali traces must be identified.

TABLE 7

Calculated Capsule Burnup Altitudes (ft)

<u>Mode of Re-entry</u>	<u>Test 3751</u>	<u>Test 5462</u>
Na sphere, stable (FPS)	243, 000	242, 000
Na sphere, spinning (FPS)	190, 000	193, 000
Na sphere, stable (Azusa)	242, 000	244, 000
Na sphere, spinning (Azusa)	190, 000	192, 000
Cs cylinder, stable, normal	239, 000	237, 000
Cs cylinder, stable, parallel	241, 000	242, 000
Cs cylinder, stable, 45°	230, 000	230, 000
Cs cylinder, spinning, normal	187, 000	188, 000
Cs cylinder, spinning, 45°	180, 000	180, 000
Cs cylinder, spinning, tumbling	172, 000	174, 000
Rb cylinder, stable, normal	233, 000	234, 000

Fig. 24. Flight Test Evaluation Program

Fig. 25. Comparison of Test and Computed Data, Test 3751

Fig. 26. Comparison of Test and Computed Data, Test 5462

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V. CONCLUSIONS

The purpose of the flight test program was to supply the experimental data with which to refine or modify the analytical techniques used in determining the mode of re-entry and fate of SNAP flight hardware. In the test program, the degree of success to be achieved was dependent upon the quantity and quality of the test data acquired. The test was well conceived to produce data of this type. Identification of the first flight's sodium trace provided an unconfirmed hint that an overly conservative heat rate has been assumed in design of operational SNAP hardware for burnup. Adjustments of the empirical heating equation, however, can be made correctly only when the corrections are based on an accumulation of repetitious test data. Failure to identify the alkalis released by the cylindrical specimens was the principal reason for the lack of sufficient data to warrant adjustment of the empirical heating equation. Refinements have been incorporated in the test program for an additional flight test.

At the present time, the significance of the test program has been

- (1) Establishing the feasibility of this testing technique.
- (2) Tentative confirmation that computational techniques used in re-entry heating analysis are sufficiently accurate to ensure conservatism in a design practice which specifies actual flight hardware for burnup upon imposition of heating encountered in tumbling and spinning re-entry.

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