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SNAP RADIOISOTOPE SPACE PROGRAMS

QUARTERLY PROGRESS REPORT NO. 6

TASK 7

January 1 through March 31, 1961

MND-P-3014-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 January 1 through March 31, 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

The efforts of this study are being applied directly in support of two specific vehicle and generator systems. A preliminary safety analysis report was issued late in the reporting period in support of the first of these systems. Adequate trajectory and vehicle data have been received. Abort trajectory and heating analyses have been initiated using machine calculation techniques.

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

Preliminary technical information derived from this study was presented at AEC and NASA. A preliminary informal report was distributed at these meetings. Conclusions drawn from this preliminary work are that the crater formed will assist in limiting contamination following impact at maximum velocity.

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

Test articles, 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. Launchings are tentatively scheduled in July for Phase I tests and August 1961 for Phase II tests. Test articles on Phase I will provide information on fuel core aerodynamic heating rates. Fuel core capsules having a constant 3/8-inch wall thickness but of four different drag configurations have been designed. Test articles on the second two shots, Phase II, will provide data on fuel core ablation rates. Fuel core capsules of identical drag configurations but varying wall thicknesses (1/4 to 5/8 inch) have been designed.

A plasma-arc experiment to verify that test articles for Phases I and II would be consumed on re-entry has been completed with positive results.

Engineering of test articles for the third phase of the study was begun late in this quarter. They will simulate the heterogeneous exterior construction of auxiliary power units. It is planned to experimentally verify the analytically predicted burnup characteristics of these devices.

The fourth phase involves analytical effort only. Studies are proceeding to define techniques for determining particulate size and subsequent dispersion of simulated radioactive fuels subjected to re-entry burnup. These studies will result in a recommended test program.

In addition to the basic 500-pound pod test program, a preliminary AFSWC 100-pound pod test is tentatively scheduled to be launched during the spring of 1961. This is expected to give an early check on the observability of flare materials and the effects of the re-entry ion sheath on telemetry capsule transmission. The Martin Company has delivered seven flame capsules and one telemetry canister for this program.

D. SUBTASK 7.4--RADIOISOTOPE SHIELDING CODE

This Monte Carlo code is designed to compute the gamma dose and flux for each energy group in certain prespecified volumes. The calculation procedure is defined by the flow diagrams included in this report. Code input information and output combinations are enumerated.

I. INTRODUCTION

This is the third 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, which was initiated late in the last reporting period, is a continuing program and deals with radioisotope flight safety analyses and tests currently under contract. Details of the scope of work are defined by a revised program plan (Ref. 1).

Task 2, relating to the SNAP 1A, 125-watt (e) generator is not included in this report. A final progress report, MND-P-3014-IV, for Task 2 covering the period from January through May 1961 will be prepared to terminate this program.

Task 3, associated with SNAP 3 development, was completed in December 1960. Contributions to SNAP Radioisotope Space Programs Quarterly Progress Report No. 5, October 1 through December 31, 1960, MND-P-3013-I, and SNAP 3 Final Performance Test Summary Addendum No. 1, March 1960, MND-P-2398, completed this task.

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

A. OBJECTIVES

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

B. SCOPE AND EVALUATION

As originally conceived, this task was general in nature although certain broad parameters were included to define the vehicle and generator combinations to be studied. Subsequent to initiation of the task, the sequence of events of other programs was such that the efforts of this study were applied directly in support of specific vehicle and generator systems.

The effort in support of the first of these systems has been adequately defined by a preliminary safety analysis report (Ref. 2) issued late in the reporting period. A trajectory and aerodynamic heating analysis to provide data for a final safety analysis report was initiated during this period. To expedite the study, assistance was obtained from the Martin Denver Division in performing the machine calculation program. The calculation runs and types of failures to be analyzed are as listed in Table 1. Trajectory and vehicle data were derived from AFBMD Reports (Refs. 3 and 4).

The second system selected for study is that planned for the Surveyor Program under the direction of Jet Propulsion Laboratory. The trajectory selected for study is one in which an Atlas-Centaur vehicle places the payload in orbit with 100-nautical mile altitude. A second

* R. J. Wilson

TABLE 1
System Trajectory Analysis

<u>Run No.</u>	<u>Type of Failure</u>
1	Nominal trajectory
2	-5 degrees azimuth, impact points
3	Nominal, impact points
4	+5 degrees azimuth error, impact points
5	-5 degrees pitch at third stage start
6	+5 degrees pitch at third stage start
7	-45 degrees pitch at third stage start
8	+45 degrees pitch at third stage start
9	-90 degrees pitch at third stage start
10	+90 degrees pitch at third stage start
11	+5 degrees yaw at third stage start
12	+45 degrees yaw at third stage start
13	+90 degrees yaw at third stage start
14	-5 degrees pitch, drag re-entry
15	+5 degrees pitch, drag re-entry
16	-45 degrees pitch, drag re-entry
17	+45 degrees pitch, drag re-entry
18	-90 degrees pitch, drag re-entry
19	+90 degrees pitch, drag re-entry
20	+5 degrees yaw, drag re-entry
21	+45 degrees yaw, drag re-entry
22	+90 degrees yaw, drag re-entry
23	Maximum q shutdown, drag re-entry
24	Second stage ignition, drag re-entry
25	Third stage ignition, drag re-entry
26	} Four shutdown times during third stage firing
27	
28	
29	

Centaur burning period will inject the payload into a transfer orbit to the moon. Although higher orbits may be used early in the program, their decay will create conditions similar to the 100-nautical mile orbit should the lunar injection stage fail to ignite. Depending on the time of launch, boost trajectory azimuths may range from 90 to 114 degrees east. Ignition of the lunar injection stage may also vary over a range of time depending upon the declination of the moon. Inclusion of this latter variable would greatly increase the scope of effort required to define the envelope of impact points following vehicle malfunction. Continued investigation revealed that the lunar injection stage will be initiated by ground command only if telemetered data indicate that satisfactory orientation has been achieved. Should guidance failure occur after ignition, a new orbit will result with characteristics determined by the mode of failure. Thus, in event of failure of either the ignition or guidance systems, random re-entry from orbit will result. For this reason, the only malfunction of this stage considered in this study will be a failure to ignite with a resulting re-entry from the 100-nautical mile orbit.

An analysis of abort trajectories based on the foregoing parameters was started late in the reporting period. Trajectory data were derived from reports furnished by Jet Propulsion Laboratory (Refs. 5 and 6). Data pertaining to vehicle weight, performance staging and range safety were obtained from Marshall Space Flight Center (Ref. 7). Although much of these data are preliminary in nature, they are the most comprehensive available for this study.

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

A. OBJECTIVES

- (1) To define the 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 define a test program to verify the analytical results determined under Items (2) and (3) and the facilities available for conducting the program.

B. SCOPE AND EVALUATION

Preliminary technical information derived from this study was presented at AEC and NASA Headquarters early in March 1961. This briefing covered the status of this study to allow the two agencies involved to reach a decision on the feasibility of designing a radioisotope-fueled generator for the Surveyor mission. Details of the information presented are contained in a preliminary informal report distributed at the meetings (Ref. 8). The following information is extracted from this report.

1. Literature Search

The impulsive properties, volume, mass, density and motion of the moon were determined by established principles and methods of celestial mechanics. Physical theories, including selenography, atmosphere, temperature and radiation, are based on optic or photographic observations as well as limited spectrographic and radiometric analyses. The exactness of the data is limited by the presence of the earth's atmosphere and by the capabilities of the optical equipment. Lunar constants of interest to this study are summarized in Table 2.

* R. J. Wilson

TABLE 2

Lunar Constants of Interest for Safety Analysis

Atmosphere	10^{-12} of earth (vacuum)
Composition	SiO_2 --quartz
Compressibility (cm^2/dyne)	16.8×10^{-13}
Density (gm/cm^3)	2.4
Escape velocity (cm/sec)	2.38×10^5
Gravitational constant (cm/sec^2)	162
Melting point ($^{\circ}\text{C}$)	1500
Meteoric impact frequency	
In space ($\text{m}^2 \text{ sec}$)	3×10^{-2}
On moon ($\text{m}^2 \text{ day}$)	7.7×10^{-7}
Specific heat of vaporization (cal/gm)	10^3
Strength of surface (dyne/cm^2)	1.98×10^9
Temperature range ($^{\circ}\text{C}$)	maximum 100 minimum 153
Thermal conductivity ($\text{gm-cal}/\text{cm-sec } ^{\circ}\text{C}$)	7.6×10^{-3}

2. Generator Configuration

A preliminary generator configuration for the Surveyor program, established under a previous study, was used for this analysis. This design will supply 19 watts of electrical power for a period of 90 days after landing on the moon's surface. Its external radiating surface is a cylinder with eight fins extending radially from the cylindrical surface. The internal arrangement is illustrated by Fig. 1. For purposes of this study, the complex structure was simplified by using an analytical model. This model consists of the generator materials arranged in layers around the fuel material in right circular cylinders. Model characteristics are summarized in Table 3.

3. Impact Study

A preliminary analysis of the impact phenomena was completed. The method of calculation used was based on equations developed by Dr. Cook and Dr. Opik.* The former's work is based on jet penetration theory while the latter's theory is that of crater formation. This analysis is also based on the conservative assumption that the moon's surface consists of quartz. A summary of significant parameters derived from this analysis is given in Table 4. The conclusions drawn from these preliminary investigations are as follows:

- (1) The fuel capsule will penetrate the quartz surface at the maximum anticipated velocity before releasing the fuel material.
- (2) The crater formed will assist in limiting the surface contamination.
- (3) The quantity of heat generated is insufficient to vaporize the capsule material.

4. Test Facilities

As a first step in defining the high velocity test program, the facilities at the NASA Ames Research Laboratory (ARL), Moffett Field, California were inspected. Their high velocity test equipment consists of two light gas guns capable of achieving velocities of 25,000 fps. Projectile specimens are limited to a maximum diameter of 20 millimeters and a weight of 10 grams. These limitations would impose a scale factor such that the validity of test results for the Surveyor program would be doubtful. In addition, their facilities cannot be utilized under direct contract and the conduct of any program would be subject to the approval of the laboratory director.

*Dr. M. A. Cook, *The Science of High Explosives*, Reinhold Publishing Corp. New York 1958
 Dr. E. Opik, *Acta Comment University Tartuensis*, 1936

Fig. 1. Soft Lunar Landing Generator

TABLE 3
Analytical Model

<u>Layer</u>	<u>Material</u>	<u>Mass</u>	<u>Volume</u>	<u>Specific Heat of Fusion (gm-cal/gm)</u>	<u>Specific Heat of Vaporization (gm-cal/gm (1 mm Hg))</u>
1	Curium	6.9	0.511	71	71
2	Tantalum	19.1	1.150	126	342
3	Hastelloy C	78.6	8.805	141	1179
4	Copper	887.65	99.068	101	1936
5	Void	--	466.0	--	--
6	316 SS	677.0	85.696	140	164
7	Lead telluride	1088.66	133.333	248	248
8	Iron	544.33	69.165	211	1344
9	Min-K	716.69	2230.530	285	285
10	Aluminum	1565.88	579.956	219	2336

TABLE 4
Impact Phenomena on Quartz

Velocity (cm/sec)

Normal landing	0
Vernier engine failure	1.5×10^4
Retroengine failure (V max)	2.74×10^5
Critical for lunar surface vaporization	1.2×10^6
Critical for generator vaporization	6×10^5
Maximum without release (no penetration)	7×10^4
Critical for penetration	7×10^4
Penetration depth at V maximum (cm)	59
Penetration volume at V maximum (cm ³)	3.3×10^4
Time of action at V maximum (sec)	5.8×10^{-4}
Heat to generator at V maximum (cal)	4.5×10^6

Discussions with personnel at ARL were helpful in defining impact and dispersion phenomena. In general their programs are oriented to determine the effect produced in the target material rather than in the projectile which is the objective of this study. It was recommended that the facilities of the Canadian Armament Research and Development Establishment be investigated. Equipment capable of accelerating full-scale specimens to the desired velocity are believed to exist at this facility. Arrangements to determine their capabilities will be initiated in the next period.

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

Progress on Subtask 7.3, Upper Atmosphere Experimental Re-entry Study, is reviewed in the following sections under sub-subtask designations as follows:

- (1) Fuel core heating and ablation (7.3.1 and 7.3.2) (Phase 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 of identical aerodynamic parameters as those in Item (2) but larger in actual dimensions. The cores used in this case will be fitted with a transmitter (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

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

2. Sub-Subtask 7.3.2--Fuel Core Ablation Studies Objectives

This portion of the program is to determine analytically and verify experimentally the ablation rates experienced by simulated fuel cores of nuclear auxiliary power systems during re-entry into the earth's atmosphere following an ICBM ballistic trajectory. 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 using an ICBM ballistic trajectory.
- (2) To design a similar core of heavy wall thickness 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 after eject from the system. AFSWC will supply this 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, Air Force Special Weapons Center (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 of the Atlantic Missile Range (AMR) during launch.

3. Design of Experiment

Based on trajectory data provided by Convair Astronautics, the average heating rate on a tumbling body during re-entry was calculated to be a maximum of 200 Btu/sec-ft². On this basis, a lead alloy containing 0.1% silver was selected to simulate fuel cores of nuclear auxiliary power systems. Geophysics Corporation of America (GCA), a company with considerable experience in flare material testing involving optical observation of particulate clouds and alkali metals, was retained as a subcontractor to recommend the type and observability of flare materials for this program. The flare materials would be contained within the lead-silver capsules. Particulate matter for day observation and alkali metals for night observation were recommended. Subsequently, nighttime launches were confirmed and sodium, rubidium, potassium and cesium were selected for encapsulation. In Sub-task 7.3.1, Phase I Testing, flare capsules of four different drag configurations will be tested to determine the effect of the configuration on penetration time. Each drag configuration is loaded with a different alkali metal so that penetration altitude and drag configuration may be correlated. The capsule configurations to be tested in Phase I are listed in Table 5.

TABLE 5
Phase I Test Capsule Configurations

<u>Shape</u>	<u>Diameter (in.)</u>	<u>Height (in.)</u>	<u>Flare Material</u>	<u>Weight (lb)</u>	<u>Wall Thickness (in.)</u>
Cylinder	2	5	Cesium	0.153	0.375
Cylinder	2.5	5	Rubidium	0.303	0.375
Cylinder	3	4-1/2	Potassium	0.26	0.375
Sphere	3		Sodium	0.163	0.375

In Sub-Subtask 7.3.2, Phase II Testing, the objective is to determine ablation rates. A single drag configuration, a cylinder 2.5 inches in diameter and 5 inches in height, in four different wall thicknesses, is used for the tests. Different flare materials are employed to permit correlation of penetration altitude with wall thickness. The test samples to be used are as follows.

	<u>Wall Thickness (in.)</u>	<u>Material</u>	<u>Amount (lb)</u>
(1)	0.25	Sodium	0.44
(2)	0.375	Potassium	0.174
(3)	0.5	Rubidium	0.207
(4)	0.625	Cesium	0.144

In Phase I a total of 32 flare capsules will be ejected from the test pod, 8 of each alkali loading; in Phase II a total of 28 capsules will be ejected, 7 of each alkali loading. For the most accurate prediction of test pod trajectory, separation from the Atlas vehicle will be made at Atlas vernier engine cutoff. So that test samples will be adequately dispersed, their ejection from the test pod will begin approximately 3.75 minutes before the re-entering pod reaches 400,000 feet. All samples containing similar alkali metals will be ejected simultaneously at approximately 4 fps; ejection of the four sample types will occur at 25-second intervals. The test pod, separated from the Atlas at 4 ± 1 fps, will be tumbling at approximately 2 degrees per second so that ejections will occur at an angular separation of about 50 degrees. In Phase I aerodynamic drag will further disperse the samples. Ejection times and velocities were selected to provide separation of samples consistent with the resolution capabilities of the observing equipment. Detectable heating of the test samples should begin at a descent altitude range of approximately 250,000 to 300,000 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 canister will weigh approximately 500 pounds. This experiment will be conducted on a noninterference basis with respect to the prime purpose of the launch.

4. Data Collection

Each test will include the ejection from the test pod of a titanium alloy telemetry canister designed to measure and transmit canister skin temperatures to downrange receiving stations. Ejection of this canister will occur two seconds after the ejection of the last set of flare capsules. Since it has not been possible to conclude that heating will not be of a local nature, a total of 26 resistance-type temperature sensing elements will be spaced symmetrically around the canister. Because an ion sheath will be generated during re-entry and may preclude receipt of data transmitted through it, the canister will contain a recorder-reproducer to record temperature data transmitted; these

data will be played back for retransmittal after a time delay of approximately 60 seconds. Delayed transmission will be completed well before the canister impacts in the ocean. The purchase of six recorders is presently being negotiated with Consolidated Electrodynamics Corporation.

Other data necessary from this re-entry experiment include flare penetration coordinates x, y, z to ± 500 feet, trajectory data including velocity and flight path angle, and the density and temperature of the atmosphere. Atmospheric data will be provided by AMR; AFSWC is charged with the responsibility of arranging for optical coverage to obtain the other data. The Geophysics Corporation of America, as a subcontractor to The Martin Company, recommended optical equipment necessary for acquisition of the data. Acting on these recommendations AFSWC has made arrangements to provide observation of the experiment in the air as well as from the ground. Ground coverage from Ascension Island will be via ballistic cameras; these will provide trajectory data. Airborne equipment, carried in a 6555th Test Wing C-54 operated by AFSWC personnel, will include K-24 and 35-mm cameras and a four-barrel photometer. The aircraft will be positioned perpendicular to the plane of the trajectory approximately 100 miles distant from the trajectory. This will provide sufficient field of view to the optical equipment. The 35-mm cameras will provide documentary coverage of re-entry; the photometers, filtered to respond to the characteristic wave lengths of the four alkali metals, will record the instant of flare capsule penetration. One unfiltered K-24 camera will be chopped to permit determination of test sample re-entry velocity; other K-24 cameras will be filtered to record the trajectory and penetration of the flare capsules. Correlation of data recorded in this manner with real time will permit determination of the information necessary to correct or verify analytical procedures for prediction of auxiliary nuclear power system fuel core re-entry heating and ablation characteristics.

5. Telemetry Experiment, 100-Pound Test Pod

The AFSWC will conduct an experiment to determine the limits placed on telemetry by the re-entry ion sheath. A 100-pound scientific test pod will be used. The telemetry canister, manufactured and delivered by The Martin Company, will be instrumented by AFSWC. No recorder will be used and sensed temperatures will be transmitted directly to the telemetry aircraft. The altitude range over which the ion sheath is effective will be evidenced by fade out of the transmitted signals. Consideration will be given to the experimental results in adjusting telemetry equipment for the 500-pound test pod to be used in Phases I and II.

Since the telemetry canister did not require the total payload of the 100-pound test pod, The Martin Company was able to make provisions for testing the flare capsules described in Table 6. Day and night materials were used because the time of Phase I and II launches had not been resolved.

TABLE 6
Capsules for 100-Pound Test Pod*

Capsule group	A	B	C	D
Flare material	K	Na	PemCo Red Stain--GS-941	Al ₂ O ₃
Color	Violet	Yellow	Red	White
Shape	Cylinder	Spherical	Spherical	Spherical
Size (in.)	2.0 x 4.5	3.75 OD	3.75 OD	3.75 OD
Actual total weight (lb)	4.03	6.1	6.47	6.33
Capsule group	E	F	G	
Flare material	Na	Al ₂ O ₃	PemCo Red Stain--GS-941	
Color	Yellow	White	Red	
Shape	Spherical	Spherical	Spherical	
Size (in.)	2.5 OD	2.0 OD	2.50 OD	
Actual total weight (lb)	2.42	1.37	2.53	

*Wall thickness = 0.375 inch.

6. Plasma Arc Model Tests

Burnup tests of scale models of the fuel core simulators (flare capsules) have been conducted in the Martin 40-kilowatt plasma facility. These tests were run to verify that the heating rates to which the test article will be subjected in Phase I and Phase II testing will cause penetration. Results of the test were positive. Tests were run at heat fluxes of 52, 85 and 231 Btu/sec-ft² and heating rates on re-entry are not expected to exceed 200 Btu/sec-ft². The tests, apparatus and data collected are presented in the section that follows.

a. Plasma jet facility

A 40-kilowatt arc-heated plasma facility was used for this work. The arc-chamber and nozzle assembly is shown in Fig. 2. The primary gas (nitrogen) enters the torch assembly and flows into a chamber where an umbrella-shaped arc is struck between the electrode and the chamber wall. The heated gas, now a plasma, passes into a plenum located upstream of a Delaval nozzle. In this chamber the primary gas is mixed with oxygen, the secondary gas, to simulate air. The gas is then expanded through the Delaval nozzle and impinged on the model mounted in a vacuum tank 1/4 inch from the exit of the nozzle.

A four-sting assembly for mounting the test models was used. This assembly allows consecutive testing of up to four models at constant settings of the facility controls. The central shaft of the assembly is outside of the tunnel housing and can be rotated at increments of 90 degrees. Devices are provided to lock the assembly at the four operating positions.

The gas enthalpy was determined by a heat balance method. The energy applied to the arc chamber was measured with a voltmeter and an ammeter. The remainder of the heat balance apparatus is shown schematically in Fig. 3. The arc chamber cooling water flow was measured with a calibrated orifice and a manometer. Cooling water temperatures upstream from the control console and upstream and downstream of the arc chamber were measured with calibrated chromel-alumel thermocouples and a galvanometer-type potentiometer. The cooling water flow rate through the Delaval nozzle walls was measured by timed weight samples. The cooling water temperature rise across the Delaval nozzle was measured with a dial-type thermometer. Nitrogen and oxygen gas flows were measured with ball-type flowmeters. Static pressures in the Delaval nozzle plenum chamber and the vacuum tank were measured with mercury manometers and a barometer.

b. Models

Heat flux calibration models. A calorimetric method was used to calibrate the plasma jet controls for the required input heat fluxes. The model configuration is shown in Fig. 4. A small copper cylinder is imbedded in a phenolic nylon holder and the junction of a chromel-alumel thermocouple silver-soldered to the rear face of the cylinder. The temperature of the rear face, as a function of time, is measured with a Minneapolis-Honeywell Visicorder (recording oscillograph).

Test models. Instrumented and uninstrumented flare models were used in the program. The latter were duplicates of the instrumented models without thermocouples and were used for visual and photographic studies of the flare models.

Fig. 2. Arc Chamber and Nozzle Assembly

Fig. 3. Schematic of Heat Balance Apparatus

Fig. 4. Calibration Model

Fig. 5. Flare Models

The re-entry flare bodies are cylindrical and spherical in shape, each with a wall thickness of $3/8$ inch. A cylindrical flare body with a 2-inch diameter by 3 inches in length was selected as a representative design. A diameter of $3/4$ inch was chosen for the scale flare models to assure uniform heating by the plasma.

It was not possible to keep the same volume ratio of lead to flare material in the scaled-down flare models. Therefore, to simulate burnup characteristics of the re-entry body in a plasma arc test, it was necessary to calculate the front wall thickness and flare material volume for the flare model. In the thickness calculation for the leading end of the model, the flare body was assumed to re-enter with its longitudinal axis parallel to the re-entry path, without tumbling. The frontal surface area to volume of lead ratio for the leading end of the $3/4$ -inch diameter flare model was equated to that ratio for the full-scale re-entry body. This gave a thickness of $3/8$ inch for the leading end of the model. The diameter ($1/2$ inch) of the flare material and the wall thickness of the cylindrical portions of the flare models were scaled relative to the re-entry body. Equating the full scale re-entry body ratio of outer surface area to volume of flare material to that of the flare model, gave the length dimension for the flare material. The resultant scale models have a $3/4$ inch outer diameter and a volume of 0.147 cubic inch of flare material (Fig. 5).

The lead containers are mounted on a phenolic nylon holder to lessen the heat conduction to the string assembly. All alkali flare materials were loaded in a dry box under argon and the screw threads between the lead container and the phenolic nylon provided with an airtight seal.

The instrumented models have an axial hole through the nylon holder to allow the ceramic insulator containing a chromel-alumel thermocouple to be inserted. Three instrumented models were used for each burnup test at a constant input heat flux. Each model contained one thermocouple with its junction located at positions A, B or C as shown in Fig. 5. The test variables are given in Table 7.

TABLE 7
Plasma Arc Test Variables

Condition	Power Input	Gas Flow		Plenum Pressure	Tank Pressure	Calibration Heat Flux	Gas Enthalpy
Symbol	Q	$\dot{m}$		P_p	T_p	$\dot{q}$	h
Units	(kw)	(SCFH)	(lb/sec)	(in. Hg abs)	(in. Hg abs)	(Btu/ft ² -sec)	(Btu/lb)
Values	12.7	125	0.0029	2.68	2.89	52	1985
	15.2	125	0.0029	2.89	3.14	85	2294
	24.4	125	0.0029	3.51	3.14	231	3607

c. Discussion of results

Photographs were taken of the burnup tests with a 70-mm camera operating at 10 frames per second and a 16-mm camera running at approximately 500 feet per second. The 70-mm film will be processed as glass slides and color prints. Observation of the flare models during burnup revealed that the front wall of the lead container progressively melted and was blown away by the plasma stream. As predicted, the higher the heat flux, the greater the light intensity from the flare material and the shorter the flash duration. The lead container appeared blue while sodium and potassium were seen as bright orange and faint violet colors, respectively.

Temperature measurements at the three experimental heat fluxes are presented graphically as temperature versus time curves (Figs. 6, 7 and 8) for each thermocouple junction position (see Fig. 5). The temperature curves for the flare models showed the following:

- (1) A short time lapse when there was no temperature rise occurred until the heat was conducted through the lead. This lapse increases with increased distance between the thermocouple and the front edge of the lead container.
- (2) The temperature rise was nearly linear at each junction position until burn-through of the leading end occurred.
- (3) After burn-through of the container, the temperature rose rapidly to the maximum deflection of the oscillograph.

Two sets of data were taken at each heat flux. The set of curves giving the most consistent data is presented in this report.

Several of the temperature curves (thermocouple positions at B and C) in the other tests showed no temperature rise until after container burn-through. This was attributed to faulty thermocouple installations.

All of the A temperature curves showed a slight temperature drop prior to exposing the thermocouple to the plasma flame (indicated by the rapid temperature rise). This decrease in temperature was believed due to a slight cooling effect as the sodium left the flare models at the instant of burn-through. The burn-through time given by both sets of A thermocouple data is plotted as a function of heat flux in Fig. 9. The experimental data indicate that the burn-through time is given by $\Delta t \sim (q)^{-0.77}$. It is felt, however, that this relationship is not a precise representation of burn-through time versus heat flux. The temperature data indicate that the initial temperature of the lead was

Fig. 6. Temperature Versus Time for Sodium Filled Flare Models

Fig. 7. Temperature Versus Time for Sodium Filled Flare Models

Fig. 8. Temperature Versus Time for Sodium Filled Flare Models

Fig. 9. Model Burnup Versus Heat Flux

somewhat different for each heat flux. Calculations were made, considering the "sink" effect of the sodium, to correct the burn-through times for a common initial temperature of 200° F. This gave the relationship, $\Delta t \sim (\dot{q})^{-0.88}$. Also, if one calculates burn-through time assuming front face heating only and considers the "sink" effect of the sodium, one obtains $\Delta T \sim (\dot{q})^{-1.12}$. Therefore, it is felt that the experimental relationship is approximate and indicates only that burn-through time is nearly inversely proportional to heat flux. A test variable not accounted for was the increased distance of the sample surface from the nozzle as melting progressed; this results in a lowered heat flux at the heated surface as ablation occurs.

B. SUB-SUBTASK 7.3.3--GENERATOR BURNUP

1. Objectives

- (1) To design a generator mockup of both a typical radio-isotope 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 analytically determine the exact position and altitude of burnup of these generator mockups through the use of the digital 709 code.
- (3) To manufacture the mockups. (At this point in the program AFSWC performs the launch phase of the study and obtains the raw experimental results. These results are reduced and compared with the analytical prediction formed in Item 2.)
- (4) To revise the IBM 709 code for heterogeneous skins and thereby refine our analytical technique.

This phase of the program is designed to determine the susceptibility of the auxiliary power units heterogeneous exterior construction to burnup during re-entry. It is difficult to accurately analyze, by standard techniques, the manner in which the metallic and insulating materials react to aerodynamic heating upon re-entry. The objective is to obtain experimental data on this phenomenon.

Approximate cross sections of the configurations to be tested are shown schematically.

Group I Isotopic Powered
Generator Mockup
(2 required per test)

Group 2 Space Reactor Mockup
(2 required per test)

Sizes, configurations and weights will not be available until about May 1961.

The mockup generators will be designed to indicate the burnup rate of the heterogeneous specimens between altitudes of 400,000 to 100,000 feet during the re-entry portion of the trajectory.

It is planned to allow the tumbling motion of the test pod to aid in the dispersion of the Group 1 and Group 2 mockup generators. Thus, an ejection velocity of the generators from the pod of 4 ± 1 feet per second is believed to be adequate. The programmed ejection sequence for the mockup generators will be similar to that described under the Phase I and II tests.

One telemetry capsule, similar to the one described under the Phase I and II tests, is required. It will be ejected a few seconds prior to the Group 2 mockup generators.

C. SUB-SUBTASK 7.3.4--HIGH ALTITUDE SAMPLING

1. Objectives

- (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 and 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 which will enable the actual determination of fuel particle size and dispersion in the upper atmosphere during re-entry.

2. Available High Altitude Sampling Techniques

Techniques in use in upper atmosphere sampling have been reviewed with the Weather Bureau, Washington, D. C.

Starting in November 1956, high altitude air samplings have been taken for radio-chemical analysis under Project Ash Can. Early techniques included only the use of balloons; however, in recent additions to the program, USAF aircraft were used.

The balloons carry sampling equipment to a predetermined altitude where an attempt is made to pass approximately 1000 standard cubic feet of air through the filters. San Angelo, Texas, and Australia are presently being used as sampling sites. At both sites, samplings are obtained once a month, at four nominal altitudes of 50,000, 60,000, 80,000 and 90,000 feet. Results of these samplings are given in Ref. 9.

The aircraft program utilizes the B-57 aircraft for low altitudes and the U-2 for the upper altitudes. These aircraft make a series of vertical profiles of particulate radioactivity in the atmosphere at four latitudes: 70 to 73° N, 32 to 35° N, 5 to 12° N and 40° S. Longitudes are dependent on operational exigencies. The altitudes sampled are 15,000, 25,000, 40,000, 50,000, 60,000 and 90,000 feet. The B-57's are equipped with wingtip filter tanks with an exposed filter area of 1.75 square feet. The U-2 uses hatch samplers with a filter area of 1.38 square feet.

The data collected give the concentration of the radioactive material in the atmosphere. As the equipment cannot be used to measure particle size, a controlled particle experiment has been suggested. Basically, the test would measure the concentration at altitude of a tracer element of known particle size. If the experiment is conducted several times, using a different particle size each time, a relationship

of particle size to air concentration may be developed. This might be used to determine the particle size of a tracer injected into the atmosphere on a re-entry experiment. During the controlled test, a tracer of known particle size would be released from a balloon. The feasibility of the test was questioned on grounds that two collecting areas are not sufficient to measure small quantities of a tracer element. A study is planned to determine how much of the tracer is required to get positive readings on or into the collecting media.

For any release, controlled or by aerodynamic heating, it was suggested that a two-month period be allowed for the horizontal dispersion of the material before any air samples are taken. It is believed that material released in the stratosphere moves horizontally in a 10-degree band during the first month. After this time, it moves vertically toward the earth. The mean resident time in the stratosphere is a function of the altitude of release. The mean resident time in the troposphere is considered to be about 30 days.

Three devices for collecting particles have been studied and further work is being done on analyzing their feasibility.

- (1) The General Mills Jet Impactor is a device used by General Mills Corporation for measuring high altitude particles. A pump is used to force large volumes of air past a specially coated gummed slide. This can be put in an electron microscope where the adhered particles are identified and measured.
- (2) A device for scattering light from particles and by means of a photomultiplier tube and an oscillograph identify and measure them.
- (3) An electrostatic device for collecting charged particles which can be measured and identified by microscopes.

Four methods of putting the devices at the desired altitude for collecting the particles have been studied and further analysis is being done. The methods are:

- (1) High altitude sounding rockets.
- (2) A particle-collecting pod on the rocket which generates particles on re-entry.
- (3) A network of balloons launched at the correct altitude by sounding rockets.

- (4) A compartment launched by a sounding rocket and brought slowly down to earth by means of rotating blades.

Of the four methods presented, the third and fourth seem most feasible at the present as their slow descent would not disturb the particles being measured and they remain at the desired altitudes for longer times.

3. Tracer Elements

It will be necessary to recommend a suitable element to simulate fueled cores for the experiment. Tentatively, it is desirable to have a radioactive tracer element and one that has a low concentration in the atmosphere. This will increase the likelihood of obtaining meaningful data. Project Ash Can has revealed that most of the known elements are present in the atmosphere to some degree. Cerium-143 and Tungsten-187 are tentative selections on the basis of their low natural occurrence and their short half lives of 33 and 24 hours, respectively. Confirmation of their natural occurrences can be provided by the Weather Bureau.

4. Analysis

The foregoing has been a discussion of the ways in which sufficient knowledge can be developed to make it possible to predict the fate of particulate resulting from re-entry burnup of fuel cores. To date, it has been assumed that particles of less than 10-micron diameter obey the Stokes-Cunningham formula for fall velocities as a function of altitude, and that the mean residence time in the stratosphere is eight months or longer. If, in addition, the fraction of radioactive material and particle size deposited in the zone of atmosphere under study are known, ground concentration and exposure rate can be calculated. During this study, an experiment will be designed to verify this calculation. The amount of tracer element that must be introduced into the atmosphere will be predicted on the basis of the assumptions listed, circulation theory and an estimate of the concentration required by the sampling technique and equipment eventually selected.

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

1. Objectives

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

- (1) A literature search on high altitude flare materials will be conducted.
- (2) Project direction of the analytical, design, manufacturing and reporting phases of Sub-Subtasks 7.3.1, 7.3.2 and 7.3.3 and 7.3.4 will be accomplished.
- (3) Technical liaison and coordination with the various Government agencies involved in this program will be accomplished. Specifically, the agencies to be contacted are: NASA, AFSWC, HQ. ARDC, Convair, AFBMD, Cape Canaveral Atlantic Missile Range and the Atomic Energy Commission.
- (4) All reports prepared in the execution of the 7.3 program will be charged to this sub-subtask.

Reporting during this quarter has consisted of monthly letters (Refs. 10, 11 and 12) and a topical report (Ref. 13). The latter was prepared by Geophysics Corporation of America, the subcontractor retained by The Martin Company to provide technical and consultation services on alkali flare material releases in the upper atmosphere.

To maintain the total program effort on schedule, it was necessary for The Martin Company to request additional funds to procure a ruggedized miniature airborne magnetic tape recorder/reproducer for use in the telemetry canisters. Consolidated Electrodynamics Corporation was selected as subcontractor for this equipment. The equipment will be procured in accordance with a formal Statement of Work presently in preparation.

In the next quarter, hardware designs will be fixed, components manufactured and delivery expedited on Phase I and II equipments in accordance with the schedule in Table 8.

Design and analytical effort will continue on the generator burnup and high altitude sampling sub-subtasks.

TABLE 8
Hardware Delivery Schedule

<u>Item</u>	<u>Units</u>	<u>Date</u>	<u>Receiving Activity</u>
Flare capsules, Phase I	3	5/9	AFSWC
Flare capsules, Phase I	1	6/1	AFSWC
Flare capsules, Phase II	4	6/1	AFSWC
Flare capsules, Phase I	64	6/15	Martin-Cocoa
Flare capsules, Phase II	28	6/15	Martin-Cocoa
Flare capsules, Phase II	56	7/10	Martin-Cocoa
Telemetry canisters	2	6/7	AFSWC
Telemetry canisters	4	6/15	AFSWC
Recorder/reproducer	2	6/12 to 6/19	AFSWC
Recorder/reproducer	2	6/19 to 6/26	AFSWC
Recorder/reproducer	2	6/26 to 7/3	AFSWC

V. SUBTASK 7.4--RADIOISOTOPE SHIELDING CODE*

A. OBJECTIVES

- (1) To develop a machine calculation code using the Monte Carlo technique to accomplish the following:
 - (a) To determine the gamma flux in photons per square centimeter per second or dose rate in milliroentgens per hour 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 per square centimeter per second) 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. Cylindrical geometry is used to divide the system being studied into regions. A region is a volume of the system bounded by two planes perpendicular to the axis of symmetry and two cylinders whose common axis is the axis of symmetry. Only one cylinder is used if the region includes the axis of symmetry. Constant length energy scale intervals are used to define the energy groups.

1. Code Description

The main flow diagram has been completed as well as diagrams for 12 of the 15 subroutines. A general flow diagram which describes how the calculation will proceed without resorting to symbols or details is given in Table 9.

The following items of information are required to form the code input:

- (1) The gamma spectrum for each isotope used in the code.
- (2) The beta spectrum for each isotope used in the code.

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TABLE 9
Generalized Flow Diagram

- (3) The microscopic cross sections (absorption, scattering, pair production).
- (4) Dose conversion factor for each energy group.
- (5) Description of geometry.
- (6) Description of the energy breakdown.
- (7) Description of the isotope used to make up a material in a region (densities, isotope code number).
- (8) Description of the number of gammas, due to bremsstrahlung and non-bremsstrahlung, to be followed from each region (the code computes the correct weighing factor for each gamma followed).

The following answers are computed by the code:

- (1) The dose due to bremsstrahlung gammas for each specified region.
- (2) The dose due to non-bremsstrahlung gammas for each pre-specified region.
- (3) The dose due to the addition of (1) and (2) for each prespecified region.
- (4) The gamma flux for each energy group in prespecified regions.

By specifying certain input numbers, it will be possible to obtain the following combinations of answers, 1 and 4; 2 and 4; 1, 3 and 4; 2, 3 and 4.

2. Flow Diagrams

The flow diagrams included in the Appendix give a detailed description of the code. The flow diagram titled Main Flow is the program which controls the flow of the calculation. Entries into and exits out of all subroutines except RANNO are controlled by Main Flow. The subroutines used are described below.

- (1) RSQVOL computes the volume of each region and squares the radii of each region. The square of the radii is used by CYLGOM.

- (2) GNOB computes the number of non-bremsstrahlung
gammas in each region and energy group that is
to be followed by the code. The subroutine also
computes the weight to be assigned to each gamma.
- (3) BREMG computes the number of gammas due to brems-
strahlung, in each region and energy group, that
is to be followed by the code. The subroutine
also computes the weight to be assigned to each
of the gammas.
- (4) XSECT computes the probabilities of scattering and ab-
sorption as well as the total macroscopic cross
section for each energy group and material in the
system. A material is defined as a mixture of
isotopes.
- (5) COORDX picks the cartesian coordinates of a gamma in a
region. The distribution of gammas starting their
life history in a region is assumed to be isotropic
within that region.
- (6) COORDA picks the direction cosines of gammas starting
their life history. The direction cosines are
assumed to be distributed isotropically.
- (7) MFPATH selects the number of mean free paths traveled
by a particle from an exponential distribution.
- (8) CYLGOM computes the distance traveled by a gamma with
direction α , β , γ , through each region from some
initial point x , y , z , to the exterior of the system
of interest.
- (9) CMONTE computes the cartesian coordinates (x , y , z) of
the point at which collision occurs given the num-
ber of mean free paths traveled to the point of
collision.
- (10) ANAEST computes the analytical estimation of flux and
dose in each region traversed by the gamma.
- (11) COLISN determines whether the collision that occurs will
be an absorption, scattering or pair production
reaction.
- (12) PAIRPR calculates the number of gammas and the energies
of the gammas resulting from a collision involving
pair production.

- (13) BORN selects the coordinates of a gamma out of born storage. Born storage contains the gammas resulting from pair production. The coordinates of a gamma include its direction cosines, its cartesian coordinates, the energy group index with which it is associated, the weight of the gamma, whether or not it is a bremsstrahlung gamma and a count of the number of times it has collided.
- (14) KNSCAT picks from an isotropic distribution the angle of scattering and gives the energy of the scattered particle.
- (15) RANNO picks a random number from a constant probability density.

The flow diagrams for CYLGOM, KNSCAT and RANNO are not included in this report.

APPENDIX

SYMBOL TABLE

The following is a description of the symbols used in the flow diagrams. An attempt has been made to make this as complete as possible although some of the symbols needed for intermediate calculations, necessary because of peculiarities of the system of coding, may have been omitted. In many cases symbols have identical definitions; this is mandatory because different values of a particular variable must be preserved in several locations and this can be accomplished only by changing the name of the variable.

ABSQ	=	$\alpha^2 + \beta^2$
Alpha	=	α = direction cosine with respect to the x axis
A(N)	=	atomic weight of element whose code number is N
(AN)	=	Avagadro's Number
ASP	=	fork in the main flow, if ASP is <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> $\left\{ \begin{array}{l} 1. \text{ subroutine BORN is entered} \\ 2. \text{ subroutine KNSCAT is entered} \\ 3. \text{ subroutine PAIRPR is entered} \end{array} \right.$ </div>
Beta	=	β = direction cosine with respect to the y axis
BN(KF,LF)	=	number of bremsstrahlung gammas to be followed from region (K,L) if a source exists in that region BN(KF,LF) is an input number
C(MN,N)	=	$\rho \frac{(MN,M)}{A(N)}$ = density of isotope number M in material MN divided by the atomic weight of the Mth element in material MN (the code number of the element is N)
CN	=	count on the number of collisions experienced by the gammas being followed

CONST	= $\rho \frac{(MN,M) \lambda (N)}{A(N)} = C(MN,N) \lambda (N)$ where $\lambda (N)$ is the decay constant of the isotope whose code number is N
CONST(2)	= $(AN) \cdot E \cdot V(K,L)$
CSIGA(MN,J)	= macroscopic absorption cross section for material MN, energy group J, divided by Avagadro's Number
CSIGP(MN,J)	= macroscopic pair production cross section for material MN, energy group J, divided by Avagadro's Number
CSIGS(MN,J)	= macroscopic scattering cross section for material MN, energy group J, divided by Avagadro's Number
CSIGT(MN,J)	= macroscopic total cross section for material MN, energy group J, divided by Avagadro's Number
(CT)	= constant = $7 \times 10^{-4} \text{ (Mev}^{-1}\text{)}$
DCN(KD,J)	= dose conversion factor for energy group J whose code number is KD. Input number
DELTA E	= ΔE = increment in energy (Mev)
DISTMX	= distance along a radius from outermost part of scattering to the outer point of the system (cm). Input
D(K,L)	= distance (cm) traveled by a gamma in region K,L
DOSEB(KR,LR)	= dose due to bremsstrahlung gammas in region identified by KR, LR. Output
DOSE(KR,LR)	= dose due to non-bremsstrahlung gammas in region identified by KR, LR. Output
E	= energy (Mev)
E(J+1/2)	= $E(J) + 1/2 \Delta E \text{ (Mev)}$
E(J)	= energy at the lower bound of energy interval J (Mev)

FINBG	= a fork set in the code	1. Follow non-bremsstrahlung gammas or stop calculation 0. Follow bremsstrahlung gammas
FOLBG(KF,LF,J)	=	number of bremsstrahlung gammas in energy group J followed by the code for a region identified by KF, LF
GN(KF,LF)	=	number of non-bremsstrahlung gammas to be followed from a region identified by KF, LF if a source exists in that region. Input
HEE(I)	=	$\frac{1}{E(I + 1/2)}$ (Mev ⁻¹)
HE(J)	=	$\frac{1}{E(J + 1/2)}$ (Mev ⁻¹)
I		index on energy groups
J		index on energy groups
JC	=	maximum number of energy groups plus one
JJ	=	count of number of particles stored in BORN
JMC	=	energy group index of the gammas due to annihilation of positrons and electrons in the pair production process
JPP	=	energy group index of particle stored in BORN
K	=	index indicating the Z region
L	=	index on the radial regions
Lambda (N)	=	$\lambda (N)$ = decay constant for isotope N ($\frac{\text{disintegrations}}{\text{sec}}$)
LLMAX(K)	=	maximum number of radial regions in axial region K. Input
LMAX(K)	=	largest radial region index for a given K region for which the distance is calculated

LMIN(K)	= smallest radial region index for a given K region for which the distance is calculated
M	= counter on the number of isotopes in a material
MFPATH	= mean free path
MMAX(MN)	= maximum number of isotopes in material (MN). Input
MN(K,L)	= material code number in region K, L. Input
MNMAX	= maximum number of different materials. Input
MP(MN,M)	= Mth code number for an isotope in material MN. Input
N	= used as a code number for isotopes in code
PALPHA(JJ)	= JJth α stored in subroutine BORN
PA(MN,J)	= probability of absorption in material MN, energy group J
PBETTA(JJ)	= JJth β stored in subroutine BORN
PCN	= collision number stored in subroutine BORN
PGAMMA(JJ)	= JJth γ stored in subroutine BORN
ρ (MN,M)	= density of the Mth isotope in material MN. $(\frac{\text{gm}}{\text{cm}^3})$. Input
PPB	= indicates if the gamma is due to bremsstrahlung or non-bremsstrahlung source. Stored in BORN
PXPP	= x coordinate used in subroutine PAIRPR
PYP	= y coordinate of the gamma stored in BORN
PYPP	= y coordinate used in subroutine PAIRPR
PZP	= z coordinate of the gamma stored in BORN

PZPP	=	z coordinate used in subroutine PAIRPR
RAS(MN)	=	$\sum_M \frac{P(MN, M)}{A(M)}$
R(K,L)	=	outer radius of region K, L. (cm) Input
RSQR(K,L)	=	outer radius squared of region K,L
S	=	fork index set in the code which decided if CYLGOM should be entered
Psi	=	random number
PS(MN,J)	=	probability of scattering for material MN, energy group J
PW(JJ)	=	weight of the JJth gamma stored in BORN
PXP	=	x coordinate of the gamma stored in BORN
SB(MP,I)	=	beta spectrum (the number of β per disintegration per atom for isotope MP, energy group I)
SG(N,J)	=	gamma spectrum (the number of γ per disintegration per atom for isotope N, energy group J)
SIGA(MP,J)	=	microscopic absorption cross section for isotope MP, energy group J. Input
SIGP(MP,J)	=	microscopic scattering cross section for isotope MP, energy group J. Input
SKIPCO	=	fork index set in the code which determines whether or not the COLISN routine should be entered
SKIPMC	=	fork index set in the code which determines whether or not the CMONTE routine should be entered
SSBB(MN,J)	=	intermediate calculation of the bremsstrahlung gammas
SSB(J)	=	$\sum_{MP} (HE(J) - HEE(I)) * SB(MP, I),$ intermediate calculation for the bremsstrahlung gammas

SSG(MN,J)	= intermediate calculation of the non-bremsstrahlung gammas
TBG	= total number of bremsstrahlung gammas to be followed
TRBG(KF,LF)	= total number of bremsstrahlung gammas to be followed from a region identified by KF, LF
TREBG(KF,LF,J)	= total number of bremsstrahlung gammas to be followed in energy group J from a region identified by KF, LF
TRESG(KF,LF,J)	= total number of non-bremsstrahlung gammas to be followed from energy group J from a region identified by KF,LF
TRSG(KF,LF)	= total number of non-bremsstrahlung gammas to be followed from a region identified by KF,LF
TSG	= total number of non-bremsstrahlung gammas to be followed
V(K,L)	= volume of region K,L
W	= weight of the gamma being followed
WANA	= weight of the gamma being followed on ANAEST
WB(KF,LF)	= weight of the bremsstrahlung gammas to be followed in a region identified by KF,LF
WG(KF,LF)	= weight of the non-bremsstrahlung gammas to be followed in a region identified by KF,LF
X	= x coordinate
XMFP(KR,LR,J)	= number of mean free paths traveled by gammas in energy group J and in a region identified by KR,LR
XMU	= number of mean free paths
XP(1)	= x coordinate used in CYLGOM
XP(2)	= y coordinate used in CYLGOM
XP(3)	= z coordinate used in CYLGOM

XPP	=	x coordinate
XST(MN,J)	=	total macroscopic cross section for material MN, energy group J
XXMFPI	=	number of mean free paths
Y	=	y coordinate
YPP	=	y coordinate
Z	=	z coordinate
Z(K)	=	z coordinate (lower bound) of region K
ZPP	=	z coordinate
ZRAS(MN)	=	$\sum_{MP} \frac{z(MP) (MN,MP)}{A(MP)}$
ZZ	=	z coordinate
ZZZ	=	z coordinate

Flow Diagrams

The main and subroutine flow diagrams are as follows:

[illegible]

SUBROUTINE RSQVOL

SUBROUTINE GNOB

SUBROUTINE XSECT

SUBROUTINE COORDX

SUBROUTINE COORDA

SUBROUTINE MFPATH

SUBROUTINE CMNTE

SUBROUTINE COLISN

SUBROUTINE PAIRPR

SUBROUTINE BORN

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