56
MASTER

SPECIFIED EXTERNAL DISTRIBUTION

SC-PR-68-409

June 1968

**AEROSPACE
NUCLEAR
SAFETY**

**AEROSPACE NUCLEAR SAFETY REPORT
FOR MAY 1968**

CLASSIFICATION CANCELLED	
DATE	6/23/72 EJT
For The Atomic Energy Commission	
Edgar J. Thurin for the	
Chief, Declassification Branch	

Exempt from CCRP Re-review Requirements
(per 7/22/82 Duff/Caudle memorandum)

NK/10/20/05

**AEROSPACE NUCLEAR SAFETY DEPARTMENT 9310
SANDIA LABORATORY**

SANDIA LABORATORIES

OPERATED FOR THE UNITED STATES ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE NEW MEXICO | LIVERMORE CALIFORNIA

DISTRIBUTION OF THIS DOCUMENT UNLIMITED
THIS DOCUMENT HAS BEEN REVIEWED,
NO INVENTIONS OF PATENT INTEREST
OR OTHER RIGHTS ARE DISCLOSED THEREIN

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia Corporation
a prime contractor to the
United States Atomic Energy Commission

—LEGAL NOTICE—

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

SPECIFIED EXTERNAL DISTRIBUTION

SC-PR-68-409

AEROSPACE NUCLEAR SAFETY REPORT FOR MAY 1968

Prepared by
Aerospace Nuclear Safety Department, 9310
V. E. Blake, Manager

Sandia Laboratory

Compiled by
E. R. Burke, 9319
R. G. Illing, 9319

ABSTRACT

This report describes research, development, support, and test activities in the Sandia Laboratory Aerospace Nuclear Safety Program for May 1968.

June 1968

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED
1-2

BLANK

SUMMARY

SNAP-19

An analysis was performed to determine the steady-state temperature of the SNAP-19 generator when it is enclosed in an 80-gallon drum following recovery of the generator from the ocean.

SNAP-27

Several live fuel impact tests and a radiant heat test on a verification capsule were completed.

SNAP-29

A detailed review of the Martin Preliminary Safety Analysis Report was completed. Comments were provided to Martin and other concerned organizations.

TRACKING, SEARCH, DETECTION, AND RECOVERY

A report documenting the January 1968 AEC meeting on tracking, search, detection, and recovery of nuclear heat sources was distributed.

DOSE MODEL

Some results from experimental alpha dosimetry work on ^{238}Pu microspheres are reported; in most cases the results compared favorably with theoretical predictions. Summary information on a study of atmospheric diffusion models for the release of ^{210}Po at high altitude is given, and some preliminary results from Colorado State University on the transfer of ^{210}Po from rumen to milk in dairy cows are reported.

BLANK

TABLE OF CONTENTS

RADIOISOTOPE SYSTEMS SAFETY SUPPORT

	<u>Page</u>
SNAP-19.	7
Recovery Operation	7
SNAP-27.	7
Safety Evaluation Schedule	8
Review of GE Safety Analysis Report	8
NASA Information for Safety Analysis Report	8
Live Fuel Impact Tests	8
Radiant Heat Test	9
Launch Abort Model	10
SNAP-29.	10
Review of Preliminary Safety Analysis Report (PSAR)	10
AEDC Fuel Block Tests	11
Capsule Burial	11
NAVSAT	12
Thermal Analysis of Two Proposed Power Supplies	12

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY	13
Effects of Helium in ZrO ₂	13
²⁴² Curium	14
Particle Dynamics Related to Small Particle Experiments in a Ballistic Gun Range	15
Analysis of Microsphere Debris	16

TABLE OF CONTENTS (continued)

	<u>Page</u>
TRACKING, SEARCH, DETECTION, AND RECOVERY	17
Report publication	17
INTACT HEAT SOURCE	18
Thermal Conductance of Soils	18
Aerodynamic and Trajectory Analyses of a Cobalt 60 Fuel Capsule	18
Cobalt 60 Thermal Analysis	20
DOSE MODEL	20
Experimental Alpha Dosimetry of $^{238}\text{PuO}_2$ Microspheres . .	20
Release of ^{210}Po at High Altitude	24
Transfer of ^{210}Po from Rumen to Milk in a Cow	24
ENVIRONMENTAL TRANSPORT MODEL	26
Stardust Atmospheric Fallout Studies	26
ABORT MODEL	26
Autorotation Studies	26
CONFAC II Computer Code	28

RADIOISOTOPE SYSTEMS SAFETY SUPPORT

SNAP-19

The SNAP-19 is a 30-watt thermoelectric generator which contains an intact reentry heat source (IRHS). Two SNAP-19 generators will be mounted in tandem on the Nimbus B experimental weather satellite and will supplement the power generated by the satellite solar panels.

Recovery Operation (D. W. Larson)

An analysis was performed to determine the steady-state temperature of the SNAP-19 generator when the generator is enclosed in an 80-gallon drum following recovery of the generator from the ocean. Neglecting convection, the drum's outer surface temperature varied from 569°F to 204°F for emissivities of 0.1 to 0.9, respectively. For a drum emissivity of 0.9 and with the generator inside the drum in air, the generator's surface temperature was approximately 510°F with fins intact and approximately 700°F without the fins. A thermal model was constructed to determine the temperature of the surface of the SNAP-19 after it was pulled from the water and placed on deck. With the generator fins intact, and considering radiative losses only, the surface reached 398°F in 60 minutes; without the generator fins the surface temperature reached 625°F in 30 minutes. A second thermal model was constructed to determine the temperature response of the 80-gallon drum when the drum is filled with water prior to placing the SNAP-19 generator in the drum. The water temperature (and drum surface) required 60 hours to reach 206°F, which is approaching the equilibrium temperature of 212°F at sea level.

SNAP-27

The SNAP-27 is a 63-watt thermoelectric power supply designed for lunar operating conditions. It will be used as the electrical power generator for the Apollo lunar surface experiment package (ALSEP). During the trip to the moon, the fuel capsule will be contained in a

graphite LM fuel cask (GLFC); this is intended to protect the capsule during atmospheric reentry resulting from possible mission aborts. Final assembly of the SNAP-27 will be performed by astronauts on the lunar surface by inserting the fuel capsule into the generator assembly.

Safety Evaluation Schedule (J. E. Taylor)

The latest SNAP-27 safety evaluation schedule established by the AEC is as follows:

Safety Analysis Report distributed	- July 28, 1968
Reentry Analysis Addendum distributed	- September 15, 1968
Interagency Panel meeting	- September 3 week, 1968
AEC Safety Evaluation Report completed	- October 15, 1968
Panel sign-off of SER	- November 1, 1968
AEC Commission review	- November 7, 1968
AEC Commission approval	- December 1, 1968
Space Council review	- December 7, 1968
Flight approval	- December 31, 1968

Review of GE Safety Analysis Report (J. E. Taylor)

Review of the GE Safety Analysis Report continues as individual sections of the report are completed in draft form by GE and submitted to Sandia for review.

NASA Information for Safety Analysis Report (J. E. Taylor)

Additional information was received from NASA on Apollo abort probabilities. Sandia and GE representatives attended a meeting at NASA/MSC on May 23 concerning additional data needed from NASA for the Safety Analysis Report, particularly information on explosive aborts, LM reentry angles, and LM breakup analyses.

Live Fuel Impact Tests (B. S. Hill)

Three live fuel impact tests were completed during this period; two contained aged, thermally cycled fuel, and one contained production grade fuel from Mound fuel batch 127 which was produced on August 10, 1967. The fuel fines resulting from the tests are being analyzed.

The two capsules containing the aged fuel were impacted into a granite target at 1000°F at an impact velocity of approximately 100 fps. The purpose of these tests is to determine the effect of aging of the fuel on the production of fines; the fines data will be compared with similar impacts of newer, production grade fuel.

The third capsule, which contained the newer production grade fuel, was impacted into a granite target at 1000°F at an impact velocity of approximately 300 fps. The purpose of this test is to determine the fines production resulting from a higher velocity impact.

Radiant Heat Test (L. L. Keller)

A verification capsule (V2) was received from GE, a test plan was prepared, and a radiant heat test (simulated fireball/afterfire thermal profile) was performed on May 28, 1968. Posttest results are not yet available, but two visual observations were made: (1) there was no obvious change to the physical dimensions, and (2) after cool-down the emissivity coating was no longer on the cylindrical surface of the capsule. The time or nature of the coating removal is not presently known, but fragments of the material were present in the test fixture under the capsule. After a preliminary examination, the capsule will be returned to GE for posttest evaluation. A report covering the test procedures, photographs, and time/temperature data for this capsule and the two radiant heat capsules will be prepared by Sandia when testing is complete.

A test plan for the SNAP-27 fuel capsule radiant heat test was received from GE. The test plan describes the test of a capsule in a GLFC experiencing earth orbit decay with (1) side-on spinning reentry and (2) side-on nonspinning reentry. The test plan is a product of Sandia's preliminary test plan and GE's thermal calculations (time versus temperature) for the capsule clad. We are reviewing the temperature profiles and test schedule to determine our ability to meet the requirements expressed by GE.

Launch Abort Model (R. E. Berry)

The fuel capsule is subjected to a fragment field when the Saturn S-IVB explodes during a launch abort. It is necessary to define this fragment field in order to analyze the probability of fuel release. Such a fragment model was prepared.

This fragment model was refined to include predictions for fuel release quantities. The model is based upon actual launch abort data, Project PYRO test data, and engineering judgement. The latter input is a judgement factor based on literature review, visits to various installations, and internal discussions about the probabilities associated with various phases of the launch abort problem. The fragment model is under continuing review and updating as information becomes available.

Visits to Lear Siegler Service Corporation and the Air Force Rocket Propulsion Laboratory were made to discuss the launch abort problem in general and a fragment model in particular. The discussions gave additional background information which improves the engineering judgement factor used in the model preparation.

SNAP-29

The SNAP-29 radioisotope thermoelectric generator (RTG) is a 400-watt (electrical) power supply designed for an earth orbital mission of 144 days maximum duration. The heat source is ^{210}Po packaged in 16 cylindrical rods. The rods are evenly spaced in a rectangular, flat graphite plate. The temperature to the thermoelectric conversion system is regulated by a thermally controlled shutter panel. The heat rejection system consists of heat pipes.

Review of Preliminary Safety Analysis Report (PSAR)

Safety Analysis Review (R. T. Finnell) -- A large number of comments were generated within Sandia as a result of a detailed review of draft copies of the Martin PSAR. Teams were established to review the comments in the following categories: Hazard Identification and Probabilities; Reentry Evaluation; Atmospheric Release; Water Release; Dose Evaluation; and Miscellaneous. A compilation of comments was transmitted to the Sandia Space Isotope Power Department, and to the AEC,

Martin, and Mound on May 9. Martin representatives visited Sandia during the week of May 13, and numerous telephone discussions took place between individuals at Sandia and Martin. A final tabulation of our comments, together with a brief statement concerning the resolution of each comment, was distributed on May 17. Although agreement was reached concerning the action on each item, several important areas in the study that will require more attention include: the rate of fuel release; the duration of fuel release before recovery; manufacturing reliabilities; pad abort analysis; atmospheric distribution hazards; and dose studies.

Aerothermo Review (A. C. Bustamante) -- The aerothermo review of the Martin PSAR on the SNAP-29 was completed. The volumes of prime concern to the Sandia Reentry and Space Sciences Division are Volume II and Appendix A (Error Analysis) of Volume III. There were no serious comments on or disagreements with Martin's aerothermo analysis as presented in the PSAR. In fact, there is good agreement between our aerothermo studies and those of Martin; this probably reflects the closely coordinated effort that has existed between Martin and Sandia since the start of the program.

AEDC Fuel Block Tests (A. C. Bustamante/D. E. Randall)

The free flight test of 10 percent scale fuel block models at Mach 8 was successfully completed. A total of 29 shots was made, with successful launches being completed in each of the four initial attitudes planned. Preliminary analyses of the data show that for some of the tests the plates had angular rates as high as 15,500 rpm and as low as 500 rpm.

Capsule Burial (F. L. Baker)

Burial tests of two simulated SNAP-29 capsules were conducted in Ottawa sand. Both units were buried horizontally, the first unit at a depth of one-half its diameter and the second at a depth of six inches. Each unit was instrumented to monitor the capsule's surface temperature and was operated for a period of 48 hours. The maximum temperature recorded on the lower surface of the first unit was 1695°F, the maximum temperature of the second unit was 2665°F.

NAVSAT

Thermal Analysis of Two Proposed Power Supplies (R. D. Klett/D. E. Berg)

The reentry thermal analysis of two proposed power supplies for the NAVSAT spacecraft was completed. The two power supplies investigated were the Isotec generator containing either the Gulf General Atomics heat source with hafnium oxide exterior coating or the Hittman heat source with Hastelloy N outer shell.

Both power supplies were studied for the following cases:

1. Orbital decay with heat source initially in the generator (stable heat source model),
2. Orbital decay with heat source initially free of the generator (both spinning and stable heat source models), and
3. Maximum heating rate abort with the heat source contained in the generator (stable heat source model).

Three conclusions which resulted from this analysis were:

1. The initial presence of the generator during reentry has no effect on the peak temperatures of the heat source,
2. The orbital decay case subjects the heat source to a more severe thermal environment than does the maximum heating rate abort, and
3. The peak temperatures of spinning heat sources are approximately 750°R lower than those of stable heat sources.

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY

Effects of Helium in ZrO₂ (C. J. M. Northrup, Jr.)

Because of current efforts to develop a solid solution of PuO₂/ZrO₂ as a fuel form, the effects to be expected from internally generated helium were examined.

Zirconia is a ceramic oxide with a distorted fluorite structure (monoclinic P2).^{*} At higher temperatures, it reverts to a tetragonal (1000°C) and then to a trigonal (1900°C) modification.^{**} It may be altered to form a defect lattice with the loss of oxygen.

For a given crystal structure, the classical hard-ball diffusion model can be used to empirically relate the ionic radius to the diffusion constant. Increasing the ionic radius of the atoms of the crystal results in a corresponding increase in the diffusion constant, and conversely, decreasing the ionic radius decreases the diffusion constant. The ionic radius of zirconium (+4) is 0.79 angstrom (versus 0.93 angstrom for plutonium (+4) and 0.97 angstrom for uranium (+4)), suggesting that the diffusion coefficient will be low.[†] The helium atom (radius 0.92 angstrom) cannot be accommodated into the simple interstitial positions without exerting significant compressive stresses on the crystal lattice. As a result, the helium atom will probably be attracted to oxygen ion vacancies. The compressive stresses exerted on the lattice may enhance coalescence of the defects. This could result in a diffusion coefficient that decreases with time as the defect concentration increases.

^{*} Goldschmidt and Thomasen, Vidensk. Skr., Mat. Nat. Kl. 2, 1923.

^{**} Palache, Berman, and Frondel, Dana's System of Mineralogy I, John Wiley and Sons, Inc., 1963.

[†] Handbook of Chemistry and Physics, 47th Edition, 1966.

The diffusion of helium has been studied in a number of ceramics with related crystal structures and ionic radii (UO_2 , PuO_2 , ThO_2 , ZrB_2 , $\text{UO}_2\text{-ZrO}_2$, etc.). Experiments showed that significant quantities of helium can be retained at lower temperatures (less than 1000°C). When these materials were supersaturated or subjected to radiation damage which produced significant defect concentrations, and if these conditions were accompanied by high temperatures or long times, the result was bubble formation, fracturing, swelling, etc. Bulk materials in general suffered more damage than small particles.

Based on available evidence, the helium retention and release properties of solid solution PuO_2 fuels should be determined as early in the development as practical.

^{242}Cm (D. J. Sasmor)

The feasibility and advantages of using ^{242}Cm as an alternate to ^{210}Po for the SNAP-29 heat source was investigated. Based on a preliminary study, it is concluded that ^{242}Cm is competitive in all respects for use in the SNAP-29 generator. Because of the large increase in safety that would result, we recommend that the use of ^{242}Cm be studied in more detail and that it be adopted as the reference fuel for SNAP-29 if at all possible.

Most of the pertinent data concerning the availability, specific power, and cost of ^{242}Cm and ^{210}Po , as well as a comparison of the amount of ^{242}Cm and ^{210}Po necessary for a SNAP-29 generator were forwarded by letter (dated May 9, 1968) to the Safety Branch, SEPO.

Some questions were raised concerning the oxidation of the Cm_2O_3 to CmO_2 in the temperature range 200° to 500°C . Discussions were held with Oak Ridge National Laboratory and Savannah River Laboratory regarding this oxidation reaction. From these discussions, we have concluded that the reaction will not necessarily be detrimental to the use of Cm_2O_3 - Am_2O_3 mixed oxide (35 percent ^{242}Cm as metal) as a heat source.

Particle Dynamics Related to Small Particle Experiments in a Ballistic Gun Range (R. M. Elrick)

In conjunction with ACDRL, Sandia is performing a series of hypervelocity ablation experiments which simulate conditions causing reentry particle ablation. Toward the longer range goal of developing an ablation model, the Sandia Aerospace Sciences Division, 5234, was asked to sample these ablation products in an attempt to obtain not only a size spectrum of the particles but to do this as a function of angle around the flight path and the time from the onset of particle breakup. About 20 samplers were designed, installed, and analyzed by 5234 for the first of two planned test series.

The primary projectile ($\sim 400 \mu\text{m}$ diameter gold sphere) was fired down a 120 foot range at a speed of approximately 22,000 fps in air at room temperature and a pressure of several torr. Some of the ablation particles formed debris craters in impact plates placed along the range and around the flight path; an impact plate was placed at the end of the range.

Several assumptions were made to correlate the size of a debris crater and its distance from the flight path to the size of the particle producing the crater and the particle's point of generation on the path. First, the results of previous hypervelocity impact studies by ACDRL relating particle size and energy to crater size for a particular impact material were used, inferring that extrapolation to smaller particles is valid. Also, the average flow conditions behind the projectile shock, which control the debris motion, were estimated from the position of certain of the largest craters and simplifications made on the equations of motion of these crater-forming particles. These simplifications were later justified. Velocities and trajectories of sized particles under the influence of this average flow field were computed from integrals of their equations of motion.

The consequence of this analysis suggests that a unique relationship exists between crater size and the size of the crater-forming particle for a definite distance from the flight path. Thus, not only can a debris size spectrum be measured but the point of generation of a debris particle can be marked on the flight path as well as the angular distribution of particles around the path.

Ablation debris larger than $1\text{ }\mu\text{m}$ was completely inventoried for the $380\text{ }\mu\text{m}$ particle traveling at 22,000 fps from the preheat section into the 4 torr flight range ($We = 44$). No mass or size distribution could be established for particles $< 1\text{ }\mu\text{m}$ because, although electron diffraction patterns showed the presence of gold on surfaces positioned to have collected only particles in this size range, the precise morphological source of the patterns could not be separated from the contaminant background. Based on the measured debris size distributions along the flight path (for particles $> 1\text{ }\mu\text{m}$) and the assumption of a log normal fit to the distributions, approximate values for the geometrical mean diameter, d_g , and the standard deviation of the logarithms of the diameters, $\log \beta_g$, were assumed. For distance, during the early stage of ablation $d_g \sim 15$ to $20\text{ }\mu\text{m}$ and $\log \beta_g$ lay between $1/2$ and 1 , while at the end of the trajectory when the $380\text{ }\mu\text{m}$ gold sphere had ablated to $\sim 125\text{ }\mu\text{m}$ diameter, $d_g \sim 2\text{ }\mu\text{m}$ and $\log \beta_g$ was again between $1/2$ and 1 .

A mass balance between the particle prior to ablation and the particle plus calculated debris after ablation indicated that 40 percent of the initial mass was unaccounted for. It is presumed the difference can be attributed to one or a combination of the following: debris particles $< 1\text{ }\mu\text{m}$, particles ablated farther upstream but out of reach of the samplers, and/or an improper correlation between particle size and velocity and the resulting crater size. As an example, if all particle sizes were estimated 13 percent low, this would account for the 40 percent difference in the mass balance.

Samplers, redesigned for increased sensitivity to particles $< 1\text{ }\mu\text{m}$ and repositioned in the flight range to sample farther upstream, were installed for the second series of ablation tests which were conducted during the first part of May; the results of these tests are being analyzed.

Analysis of Microsphere Debris (J. Hudson)

The analysis of the fines which resulted from stirring $^{238}\text{PuO}_2$ microspheres immersed in water is continuing. The debris was generated at Los Alamos Scientific Laboratory and was furnished to Sandia for analysis as a dry powder. This debris was sampled and then allowed to stand in distilled water without stirring.

A sample was taken after the debris had been allowed to stand in the water for twenty-seven days. The size distribution, determined by alpha counting, nuclear emulsion, and optical techniques, is shown in Table I. Figure 1 shows the results of the analysis. The debris as received and the debris after twenty-seven days in water are log-normally distributed. The arithmetic mean diameter of the debris as received is 1.9 μm , and the arithmetic mean diameter of the debris after twenty-seven days in water is 1.2 μm . Another sample of the debris was taken after standing in water for fifty-four days; the analysis is almost complete.

TABLE I
Debris After Twenty-Seven Days in Water

Diameter of the Particulate (μm)	Percent of the Total Mass
0.250	6.9
0.250 - 0.500	11.5
0.500 - 0.750	12.6
0.750 - 1.0	10.7
1.0 - 2.0	31.8
2.0 - 3.0	26.5
3.0	--

TRACKING, SEARCH, DETECTION, AND RECOVERY

Report Publication (R. G. Illing)

A report documenting the AEC meeting on tracking, search, detection, and recovery of nuclear heat sources, which was held at Sandia Laboratory on January 16-18, was distributed.*

*SC-M-68-148, AEC Meeting on Search Detection, and Recovery of Nuclear Heat Sources (U), Sandia Laboratory, Albuquerque, New Mexico, April 1968, RS 3410/1149 (SFRD).

Figure 1. Size distribution of debris

INTACT HEAT SOURCE

Thermal Conductance of Soils (J. B. Boyd)

Work under this contract with the National Bureau of Standards (NBS) is nearing completion. Data comparisons have not been possible because of a heavy computer workload.

Aerodynamic and Trajectory Analyses of a Cobalt 60 Fuel Capsule (H. R. Spahr)

The configuration analyzed was a right-circular cylinder fuel capsule 3.5 inches in diameter and 5.7 inches long, weighing 34 pounds. The capsule was assumed to be in a crosswise orientation. Free molecule flow theory was used to compute a hypersonic free molecule flow ballistic coefficient for an S number of 14 and the steady-state space surface temperature of 1998°R. Modified Newtonian flow theory was used to compute a hypersonic continuum flow ballistic coefficient, including a correction for the finite aspect ratio of the cylinder.

Computer code HRS015 was used with the Sandia Quicktran remote terminal and the IBM 7040/44 in Los Angeles to compute the variation in ballistic coefficient in the transition flow regime. Figure 2 presents the hypersonic ballistic coefficient as a function of altitude for the fuel capsule.

Figure 2.

Variation of hypersonic
ballistic coefficient
with altitude for a
cobalt 60 fuel capsule,
reentering crosswise

The results of computer code HRS004 were used to define a set of initial conditions for an orbital decay trajectory, assuming the fuel capsule was initially in a polar orbit and started reentry by itself. The initial reentry angle was -0.013° and the initial inertial velocity was 25,698.51 fps, with the reentry assumed to start at a latitude of 0° .

The Sandia TTA trajectory code was then used to compute the orbital decay trajectory for the fuel capsule. The resultant trajectory had a maximum convective aerodynamic heating rate parameter, $\dot{q}_c \sqrt{R}$, of 327 Btu per foot^{3/2} sec. This trajectory provided the reentry environment for the thermal analysis of the fuel capsule.

Cobalt 60 Thermal Analysis (D. W. Larson)

A one-dimensional thermal model of a proposed ^{60}Co -fueled SNAP system was constructed. The cobalt fuel was enclosed in a cylindrical tungsten heat accumulator with a 3.5 inch diameter and a 5.7 inch length. The temperature response of the system during an orbital decay reentry was determined, and the tungsten heat accumulator reached a maximum temperature of 4000°F for a crossflow-spin reentry mode.

DOSE MODEL

Experimental Alpha Dosimetry of $^{238}\text{PuO}_2$ Microspheres (W. L. Holley)

This work was performed at Oak Ridge National Laboratory under Sandia contract.

The alpha spectrum was obtained from a PuO_2 microsphere with an NE-102 plastic scintillator and analyzed in a Nuclear Data Model ND-110, 128 channel analyzer. Five microspheres were prepared, and each was placed on a plastic adhesive tape and fixed in an inverted position over the plastic scintillator which was coupled through a lucite light pipe to a phototube. The spectra were converted into absorbed dose by the computer program DOSEW. Corrections were made for nonlinearity of scintillator response, stopping power ratios, and channel bandwidth variations.

All measurements were made at pressures less than 150×10^{-3} torr; source to detector distances varied from 5.45 to 12 centimeters. The absorbers were films of Mylar (polyethylene terephthalate) whose thicknesses were measured with a Zeiss light-section microscope.

Table II lists the measured dose rates from the five $^{238}\text{PuO}_2$ microspheres as a function of absorber thickness and source-detector distance. Assuming that little, if any, scattering of the alpha particles takes place in the vacuum counting chamber, one can extrapolate, using the inverse square law relationship, and arrive at a value for the dose rate at the surface of the particle. Table III gives the results of these calculations along with an estimate of the relative activity of the particle in terms of $\text{rad-sec}^{-1}\text{-microcurie}^{-1}$. Both sets of values are shown in Figure 3. The calculated dose rate, in

rads per second, appears to be independent of particle size and contained activity. ORNL believes this is because the range of the alpha in PuO_2 is short enough for the spheres to appear as infinitely thick sources.

TABLE II
Measured Dose Rates from $^{238}\text{PuO}_2$ Microspheres as a Function of Absorber Thickness and Source-Detector Separation

Source No.	Diameter (μm)	Activity (μCi)	Distance (cm)	Dose Rate (Rads/hour)				
				0	Absorber 6.38	Thickness 14.4	(μm) 20.78	26.60
M - 13	225	693	12	78.73	53.91	27.79	11.44	2.534
M - 8	148	204	7	90.12	62.39	32.57	13.78	4.547
M - 12	175	357	5.45	256.6	173.8	87.57	39.27	8.219
M - 14	219	704	9.05	144.77	102.2	51.63	22.76	4.175
Gp 4 #1	123	70.2	7.25	71.74	49.20	25.03	10.50	2.291

TABLE III
Extrapolated Values at Surface of $^{238}\text{PuO}_2$ Microspheres

Source No.	Diameter (μm)	Activity (μCi)	Dose Rate $\text{Rad}\cdot\text{Sec}^{-1}$	Effective Activity $\text{Rad}\cdot\text{Sec}^{-1}\cdot\mu\text{Ci}^{-1}$
Gp 4 #1	123	70.2	27,720	395
M - 8	148	204	21,810	107
M - 12	175	357	27,810	77.4
M - 14	219	704	27,470	39.0
M - 13	225	693	24,880	35.9
		Average	25,910	
		S.D	$\pm 2,580$	

The average surface alpha dose rate was found to be $25,910 \pm 2,580$ rads per second or 9.33×10^7 rads per hour for the five sources used. This compares closely with the calculated value of 9.6×10^7 rads per hour reported by LASL for a $188.93 \pm 20.52 \mu\text{m}$ diameter $^{238}\text{PuO}_2$ microsphere.

Calculations of the dose rate per unit contained activity, as a function of particle size, gives an indication of the relative amount of radiation escaping from the microspheres. For example, in Figure 3 it can be seen that on the surface of a particle 125 μm in diameter the dose rate is ten times greater per microcurie of source activity than is the dose rate from a particle 225 μm in diameter.

As thicker absorbers were interposed, the maximum alpha energy observed decreased. Using a 41 μm thick absorber, there is little, if any evidence of alpha radiation, and the calculated dose rate is $\sim 1.95 \times 10^{-3}$ rads/minute, or <0.003 percent of the value for zero absorber thickness. Consequently, for practical purposes ORNL assumes that the range of the alphas emitted by these microspheres will be less than 41 μm in tissue. NUS Corporation has theoretically determined the $^{238}\text{PuO}_2$ alpha range to be 40.5 μm . A graph of dose rate versus absorber thickness for microsphere M-13 is shown in Figure 4.

Figure 3.
Alpha dose rate at surface
of ^{238}Pu microspheres

Figure 4.
Measured alpha dose rate from
 $^{238}\text{PuO}_2$ microspheres M-13 at
7.0 centimeters

Release of ^{210}Po at High Altitude (R. J. Everett)

Three atmospheric models were compared relative to their tropospheric predictions for a large ^{210}Po release at high altitude. The resultant time-integrated concentrations were converted to dose and applied to the general population. Individual dose and total man-rem were compared to radiation standards and criteria currently in use in the aerospace community. The Stardust model gave levels several orders of magnitude lower than the three-compartment models. The means of evaluating a release of this type using threshold and linear theories of risk was also described. Table IV gives the results of computations for a 10^6 Ci release of ^{210}Po using the three models.

TABLE IV
Results of 10^6 Ci Release of ^{210}Po

Model	Half Residence-Time (Yrs.)			Average $\bar{x}^1$ $\left(\frac{\text{Ci-sec}}{\text{M}^3}\right)$	Lung Dose per Person ²	Man-rem
	Mesosphere	Stratosphere	Troposphere			
GE ³	10	5	0.16	4.73×10^{-7}	2.83×10^{-3}	9.59×10^6
Smith ⁴	2	0.67	0.16	1.27×10^{-7}	7.61×10^{-4}	2.58×10^6
Stardust ⁵	--	--	--	2.50×10^{-9}	1.50×10^{-5}	5.08×10^4

¹Time integrated air concentrations ($\bar{x}$) were computed over a 7 year period.

²The world population was taken to be 3.39×10^9 .

³SNAP-27 Safety Analysis Report, Vol. I DIN:6300-299 - General Electric Co.

⁴Sandia Corporation - personal communication.

⁵Release at 37.5km and 17° 27' south latitude.

Transfer of ^{210}Po from Rumen to Milk in a Cow (M. A. Parsont)

A recently completed experiment at Colorado State University, in which the transfer of ^{210}Po from rumen to milk in a cow was determined, yielded the results presented in Figures 5 and 6. The equation for the secretion of ^{210}Po in milk after acute ingestion (Figure 5) was a two-component exponential with half times of 3.7 days and 33 days. Figure 6 shows ^{210}Po milk concentrations at any time after the start of intake by the cow. The minimum concentration of pasture-deposited ^{210}Po necessary to produce an MPBB was calculated to be $0.4 \mu\text{Ci}/\text{m}^2$.

Figure 5. ^{210}Po concentration in milk as a function of time after ingestion

Figure 6. ^{210}Po milk concentrations at any time after initial ingestion

ENVIRONMENTAL TRANSPORT MODEL

Stardust Atmospheric Fallout Studies (R. E. Smith)

The data published by the AEC Health and Safety Laboratory (HASL) on SNAP-9A plutonium surface air concentrations as measured in the World Wide Sampling Network were plotted against the simulated SNAP-9A injection as determined by the Stardust fallout model. In general, reasonable agreement is present, especially in the shape of the curves showing the variation in air concentrations over seasonal periods. However, the Stardust model indicated too much material entering the northern hemisphere and not enough material in the southern hemisphere when compared to the observed data. A trip is planned early in July to discuss the problem with Isotopes, Inc., and HASL in an attempt to resolve the problems for future simulated injections.

ABORT MODEL

Autorotation Studies (A. C. Bustamante/G. W. Stone)

Another autorotation test series was completed at the Army Edgewood Arsenal wind tunnel facility. A total of 144 runs was conducted, and a total of 13 configurations was tested. Preliminary analyses of data show good agreement with previous test results.

Analysis of the photographic data obtained during the Phase III autorotation wind tunnel test in September 1967 at Edgewood Arsenal was completed. Approximately 7000 feet of 16 mm film records were converted to digital records of the model's angular position variation with time. The digital data represented 138 runs on 10 flat plate models with rectangular, circular, and triangular planforms.

The digital data were analyzed on the CDC 3600 computer using the OSCIL and AUTOSPIN programs to compute static and dynamic aerodynamic coefficients from the model motions. The OSCIL computer program uses least squares numerical techniques to find the "best" damped or undamped cosine wave that fits the oscillatory model motion; it computes the effective linear static and dynamic moment coefficients from the parameters of the "best" cosine wave. By using the program for analyzing

3-cycle segments of the data, it was possible to determine the effective nonlinear static and dynamic coefficients. The AUTOSPIN computer program uses least squares numerical techniques to compute the total angular energy from the autorotation motion of the tumbling models. Using the nonlinear autorotation theory for a 1-degree-of-freedom system presented by Bustamante and Stone*, it is possible to calculate the instantaneous dynamic moment coefficient from the total angular energy of the system.

A typical effective static moment coefficient variation with angle of attack is shown in Figure 7 for the oscillating motion of the fuel puck model. The dynamic moment coefficient was found to correlate with the square of the reduced frequency, and the variation of this coefficient with the correlation parameter is shown in Figure 8 for both oscillatory and autorotation motions of the fuel puck model. Figure 8 shows the typical stability boundary between oscillatory and autorotational motions of flat plate models. The data from Figures 7 and 8 can be used with moment of inertia and trajectory data to compute the flight dynamic characteristics of any size of fuel puck vehicle.

Figure 7. Typical variation of the effective static moment coefficient with angle of attack

*SC-RR-67-778, Autorotational Characteristics of Flat Plates and Right Circular Cylinders at Subsonic Speeds, A. C. Bustamante and G. W. Stone, Sandia Laboratory, Albuquerque, New Mexico, November 1967.

Figure 8. Typical variation of the dynamic moment coefficient with the square of the reduced frequency

CONFAC II Computer Code (D. W. Larson)

A North American Aviation computer code for determining radiant-exchange configuration factors is currently running on Sandia's IBM 7090. Comparisons between the code's calculated values and values which can be obtained in a closed form solution for specified geometrical shapes indicate that the values determined by the program are correct.

SPECIFIED EXTERNAL DISTRIBUTION

DISTRIBUTION:

U. S. Atomic Energy Commission
Division of Space Nuclear Sys.
Space Electric Power Office
Washington, D.C. 20545 (6)

Attn: G. A. Newby
Assistant Director
G. P. Dix, Chief
Safety Branch
R. S. Decker, Jr., Chief
Safety Branch
R. T. Carpenter, Chief
Isotope Power Sys. Br.
J. A. Powers, Chief
Isotope and Matls. Br.
C. Johnson, Chief
Reactor Power Sys. Br.

U. S. Atomic Energy Commission
Director of Regulation
Washington, D.C. 20545 (2)
Attn: C. K. Beck, Deputy Dir.
F. D. Anderson, Regulation

U. S. Atomic Energy Commission
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115 (2)
Attn: S. A. Upson, Director
Non-Weapons Activities Div.
J. F. Burke, Director

U. S. Atomic Energy Commission
Canoga Park Area Office
P.O. Box 591
Canoga Park, California
Attn: D. E. Reardon

Air Force Weapons Laboratory
Kirtland Air Force Base
New Mexico
Attn: Maj. K. D. McAllister
(WLAS)

Monsanto Research Corporation
Mound Laboratory
P.O. Box 32
Miamisburg, Ohio 45342
Attn: G. R. Grove

Thomas B. Kerr
Code RNS
National Aeronautics and Space
Administration
Washington, D.C. 20546
U. S. Naval Radiological Defense
Laboratory
Commanding Officer and Director
San Francisco, California 94135
Attn: S. Z. Mikhail
AEC Site Representative
NASA
Manned Space Center
Houston, Texas 77058
Attn: W. C. Remini
Bldg. 16, Code ZS-5

J. D. Shreve, 5234
L. E. Lamkin, 7300
G. A. Fowler, 9000
A. Y. Pope, 9300
Attn: V. E. Blake, 9310
H. E. Hansen, 9311
S. L. Jeffers, 9312
S. McAlees, 9314
R. J. Everett, 9315
J. D. Appel, 9319
J. D. Appel, 9319 (ANSIC) (2)
R. C. Maydew, 9320
A. J. Clark, 9330
J. W. McKiernan, 9331
R. P. Stromberg, 9333
B. F. Hefley, 8232 (5)
B. R. Allen, 3421
C. H. Sproul, 3428-2 (5)
L. C. Baldwin, 3412
L. L. Alpaugh, 3412