Dr-1205

SPECIFIED DISTRIBUTION ONLY

SC-PR-69-881
January 1970

149
2-3-70

MASTER

**AEROSPACE
NUCLEAR
SAFETY**

SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER 1 THROUGH DECEMBER 31, 1969

DR-1205

AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY G. H. Kahn
DATE 2/13/70

P4115

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SANDIA LABORATORIES

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.

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

SPECIFIED DISTRIBUTION ONLY

SC-PR-69-881

SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER 1 THROUGH DECEMBER 31, 1969

Prepared by
Aerospace Nuclear Safety Department 9510
A. J. Clark, Jr., Manager

Sandia Laboratories, Albuquerque

Compiled by
R. G. Illing, 9512

January 1970

ABSTRACT

This report describes research, development, support, and test activities in Sandia Laboratories Aerospace Nuclear Safety Program from October 1 through December 31, 1969.

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.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
PLG

page blank

SUMMARY

TRANSIT

Sandia impact tested five Transit design capsules which were fabricated by Atomics International (AI); all capsules were returned to AI for postmortem. Ten solid propellant burn tests have been conducted at Sandia to date; good data obtained on nine tests are being compared to the theoretical thermal model, and agreement between the two appears good. The thermal responses of the AI/T-111 and the Isotopes/TZM capsules in the Transit and Pioneer heat sources will be compared; TRW Systems will conduct the study for the Transit mission based on Sandia-supplied trajectories, heating rates, and material properties.

PIONEER/VIKING

Five Isotopes capsules were impact tested using the Sandia sled track facility; four capsules broke open at impact. An analysis was conducted to determine the ablation which would occur during orbital decay and multiple orbit reentry of the Isotopes hexagonal heat source enclosing: (1) the AI/T-111 capsule, or (2) the Isotopes/TZM capsule; both capsules were predicted to survive multiple orbit reentry from 260 kft perigee and orbital decay for all combinations of components. In simulated orbital decay heat pulse testing, the heat shield was burned through to the threads of the end plug.

ADVANCED FUELS SAFETY

Molybdenum wires approximately 100 μm in diameter were exposed to alpha particle doses simulating $^{238}\text{PuO}_2$ cermet fuels 1 to 5 years old; room temperature tensile tests on wires exposed to 5-year simulants indicated that the ultimate strength increased by approximately 3 percent while the percent elongation was reduced about 40 percent. Two LASL-fabricated ThO_2 specimens were exposed to simulated reentry heat fluxes in the Sandia 40-kW arc tunnel for 30 seconds; neither specimen experienced any melt, ablation, or thermal fragmentation.

ABORT MODEL

An investigation is underway to determine if particle detectors in a laminar flow cleanroom background are useful for detecting leaks in impacted RTG heat source fuel capsules. An effort is underway to determine structural scaling laws for application to fuel capsules subjected to blast, fragment or earth impact, and thermal loading.

TABLE OF CONTENTS

RADIOISOTOPE SYSTEMS SAFETY SUPPORT

	<u>Page</u>
SNAP-27	7
GLFC Multiple Revolution Reentry Analysis	7
GLFC Thermal Analysis	7
ALRH Multiple Revolution Reentry Analysis	7
TRANSIT	7
Fuels Impact	7
Fuels Impact Facilities	8
Task 8 Impact Tests	9
Solid Propellant Burn Tests	35
Aerodynamic and Trajectory Analyses	42
Initial Reentry Conditions for Transit Heat Source	42
Heat Shield Ablation Analysis	42
Investigations Involving Transit Heat Source	43
PIONEER/VIKING	44
Isotopes Capsules Comparative Tests	44
RTG Data Submittal Plan	49
Multiple Orbit Reentry Comparative Ablation Analysis	49
Pioneer/Viking Proposals by Isotopes	49
ISOTOPE BRAYTON HEAT SOURCE (IBHS)	51
Proposed Nuclear Safety Criteria	51
Operational Temperature Thermal Analysis	51
Radiation Configuration Factors	51
Superorbital Velocity Reentry Protection Requirements	51

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY	53
Alpha Deposition in Cermets	53
Tensile Response of Alpha Irradiated Molybdenum	57
Alpha Radiation Damage in Molybdenum	58
Reentry Ablation Testing in a Hyperthermal Arc Tunnel	67
Similarity Analysis	67

TABLE OF CONTENTS (continued)

	<u>Page</u>
FLIGHT TEST STUDIES	69
Reentry Simulation	69
INTACT HEAT SOURCE	70
Response of Structures Constructed of Plastically Anisotropic Materials	70
DOSE MODEL	71
Radiation Risk Criterion	71
ABORT MODEL	71
Leak Detection	71
Scaling Laws for Fuel Capsules Subjected to Blast, Impact, and Thermal Loading	72
Fuel Disc Earth Impact Simulation Techniques	73
Emissivity Switch	74
Thermal and Stress Analysis Code	74
Thermal Conductivity Tests of Carbitex-500	74
Aerodynamic Drag Analysis	75
Multiple Revolution Reentry Meeting	75
COMPUTER CODES	76
Douglas Arbitrary Body Computer Code On-Line Graphics Capability	76
SIRNETCO	76
CONVRT	76
HRS015	76
HRS016	76
HRS017	77
Radiative Reentry Heating Code	77
RADHTG	77

RADIOISOTOPE SYSTEMS SAFETY SUPPORT

SNAP-27

GLFC Multiple Revolution Reentry Analysis (H. R. Spahr)

The trajectories and reentry environments for the SNAP-27 Graphite Lunar Module Fuel Cask (GLFC) multiple revolution reentry analysis were defined in Sandia report SC-RR-69-297, Trajectories and Reentry Environments for the SNAP-27 GLFC During Multiple Revolution Highly Elliptical Orbital Decay After Supercircular Velocity Reentry; the report was distributed in December 1969.

GLFC Thermal Analysis (D. W. Larson)

An analysis was conducted to determine the thermal response of the GLFC following its insertion into a 40-gallon barrel filled with water. The results indicated a bounding steady-state temperature of 200°F with a barrel external emissivity of 0.74 or higher. A minimum of 19.7 hours is required to increase the water temperature from 70° to 200°F.

ALRH Multiple Revolution Reentry Analysis (H. R. Spahr)

The trajectories and reentry environments for the ALRH multiple revolution reentry analysis were defined in Sandia report SC-RR-69-360, Trajectories and Reentry Environments for the ALRH During Multiple Revolution Highly Elliptical Orbital Decay After Supercircular Velocity Reentry; the report was distributed in October 1969.

TRANSIT

Fuels Impact (W. J. Dalby)

Four specimens furnished by LASL were impacted at Sandia and returned to LASL for particle size distribution analyses. The specimens were approximately 0.5 inch in diameter by 0.22 inch thick. They did not have a molybdenum coating. Table I gives the temperatures and velocities at which the specimens were impacted.

TABLE I
Transit Fuels Impact

Material	Temperature (°F)	Velocity (fps)
ThO ₂ -Mo solid solution cermet simulant	835	133
ThO ₂ -Mo solid solution cermet simulant	860	125
²³⁸ PuO ₂ -ThO ₂ -Mo solid solution cermet	860	125
²³⁸ PuO ₂ -ThO ₂ -Mo solid solution cermet	880	133

Fuels Impact Facilities (W. J. Dalby)

In anticipation of continuing requirements for impact testing of radioisotope fuels, the Systems Environmental Testing Department has designed an appropriate facility. This facility will accelerate a large test container vertically upward within a large tube by the application of air pressure. At the top of the tube, the test container will be stopped and the fuel specimen will impact the rigid upper surface of the test container. In essence there will be a free-flight, unconstrained impact into a hard target but the entire action will occur within a closed container. This facility will permit control of the impact attitude of the specimen by placing it on the properly contoured bottom of the capsule where it would be held by gravity and acceleration until the planned impact.

The test container will be sealed into the top end of the launch tube during the impact phase so that in the unlikely event of container failure the fuel will not be released to the atmosphere. The facility is expected to have a velocity capability of up to 600 fps and a fuel temperature capability of about 1000°F. All of the components have been purchased, and tests of the sealing capability of the upper end of the launch tube are in progress.

Task 8 Impact Tests (L. L. Keller)

The Capsule Technology Program at Atomics International (AI) was redirected to support the Transit program. Under Task 8 of the Capsule Technology Program, a total of five Transit design capsules were fabricated and supplied to Sandia for impact tests. Three of these capsules were enclosed in graphite heat shields which were fabricated and supplied by TRW Systems. These capsule/heat source assemblies have been designated AIT8-1, AIT8-2, AIT8-3, AIT8-4, and AIT8-5. The test specimen definition, test parameters, and test status are as follows.

AIT8-1 -- The test specimen was a bare capsule similar to the current Transit flight capsule design for microsphere fuel except: (1) a fuel simulant (tungsten/molybdenum granular powder) was used, (2) a platinum/10 percent rhodium clad was used, (3) there was no burst diaphragm in the pressure relief device (PRD), (4) there were no vent holes in the strength member, and (5) there was no vent hole or burst diaphragm in the clad.

The test specimen was impacted in the turnaround mode (stationary test specimen, moving target) on October 23, 1969, using the Sandia sled test facility. The test parameters at impact were:

1. Target material - black Escondido granite;
2. Orientation - test specimen principle axis at 45 degrees to the target face and the velocity vector (Figure 1);
3. Velocity - 353 feet per second; and
4. Estimated temperatures - 1930°F clad, midpoint
1927°F clad, impact end
2090°F strength member.

The catch box failed to contain the capsule after impact, and the capsule sustained extensive secondary impact damage when it came in contact with the rocket sled. The capsule fragments (Figure 2) were returned to AI. No postmortem other than visual examination was conducted.

AIT8-2 -- The test specimen was a bare capsule similar to the current Transit flight capsule design for solid solution cermet (SSC) fuel except: (1) a fuel simulant (molybdenum/thoria solid solution cermet simulant (SSCS) was used, (2) a platinum/10 percent rhodium clad was

used, (3) there was no burst diaphragm in the PRD, (4) there were no vent holes in the strength member, and (5) there was no vent hole or burst diaphragm in the clad.

The test specimen was impacted in a turnaround mode on October 27, 1969, using the Sandia sled test facility. The test parameters at impact were:

1. Target material - black Escondido granite;
2. Orientation - test specimen principle axis at 45 degrees to the target face and the velocity vector (Figure 3);
3. Velocity - 385 feet per second; and
4. Estimated temperatures - 1990°F clad, midpoint
1910°F clad, impact end
2150°F strength member.

The capsule was contained by the catch box following impact. Visual examination disclosed considerable capsule distortion (Figures 4 and 5) but no breaching of the clad. There was no detectable radioactive contamination on the capsule surface following impact. The capsule was returned to AI where postmortem is in process. Preliminary observations by AI are:

1. The clad was leak tight when checked with helium,
2. The strength member was leak tight when checked with helium,
3. The liner was severely cracked and very brittle (Figure 6),
4. The SSCS discs were severely fractured (Figures 7 and 8), and
5. Some embrittlement of the strength member was evident during postmortem (Figure 9).

The PRD was returned to TRW for postmortem. The SSCS material was sent to LASL for postmortem. The liner and strength member are undergoing chemical and metallographic analysis at AI.

Figure 1. AIT8-1 test setup

D69-15537

Figure 2. AIT8-1 test fragments

Figure 3. AIT8-2 test setup

Figure 4. AIT8-2 test specimen after impact

Figure 5. AIT8-2 test specimen after impact

Figure 6. AIT8-2 postmortem showing cracked liner

Figure 7. AIT8-2 postmortem showing fractured SSCS

Figure 8. AIT8-2 postmortem showing fractured SSCS

Figure 9. AIT8-2 postmortem showing brittle crack in strength member

AIT8-3 -- The test specimen was a heat source assembly similar to the current Transit flight heat source design except: (1) the capsule was identical to AIT8-2, (2) the outer heat shield was made from ATJ graphite, and (3) the inner heat shield was omitted.

The test specimen was impacted in a turnaround mode on October 28, 1969, using the Sandia sled test facility. The test parameters at impact were:

1. Target material - black Escondido granite;
2. Orientation - test specimen principle axis at 45 degrees to the target face and the velocity vector (Figure 10);
3. Velocity - 387 feet per second; and
4. Estimated temperatures - 2090°F clad, midpoint
2080°F clad, impact end
2106°F strength member
1900°F graphite.

The capsule was contained by the catch box following impact. Visual examination disclosed considerable capsule distortion and a breaching of the clad in the mid-capsule area on the side opposite the impact face (Figure 11). The breach was a circumferential crack about 2 inches long. There was no detectable radioactive contamination on the capsule surface following impact. The capsule was returned to AI where postmortem is in process. Preliminary observations by AI are:

1. The clad, strength member, and liner were breached where the visual observation was made (Figures 12 and 13);
2. The strength member indicated embrittlement after impact (Figure 14);
3. The liner was badly embrittled, although there were indications of ductility during impact (Figure 13);
4. The SSCS discs were severely fractured (Figure 15); and
5. The PRD was broken into three pieces (Figure 16).

The PRD was returned to TRW for postmortem. The SSCS material was sent to LASL for postmortem. The liner and strength member are undergoing chemical and metallographic analysis at AI.

Figure 10. AIT8-3 test setup

Figure 11. AIT8-3 specimen after impact showing breached clad

Figure 12. AIT8-3 specimen after impact showing breached clad and strength member

Figure 13. AIT8-3 specimen after impact showing breached liner

Figure 14. AIT8-3 specimen after impact showing brittle crack of strength member that occurred during postmortem

Figure 15. AIT8-3 specimen after impact showing fractured SSCS

Figure 16. AIT8-3 specimen after impact showing fractured PRD

AIT8-4 -- The test specimen was a heat source assembly similar to the current Transit flight heat source design except: (1) the capsule was identical to AIT8-2 (except the clad was platinum/20 percent rhodium), and (2) the outer heat shield was made from AXM-5Q graphite.

The test specimen was preconditioned in a 24-hour thermal soak test November 21 and 22, 1969. The thermal soak test was performed in a vacuum furnace with a pressure of about 10^{-6} torr. The temperature during the test was: (1) capsule - 1319° to 1346°F, and (2) vacuum chamber - 1328° to 1346°F. Heat-up and cool-down were also performed in a vacuum. The test specimen was also preconditioned in a high enthalpy arc tunnel (HEAT) facility. A programmed heating rate pulse which approximates earth orbit decay, side-on stable reentry was used. Prior to the start of the plasma jet, the heat source was preheated (Figure 17) to minimize thermal stress. The HEAT pulse resulted in burnthrough of the outer heat shield wall (Figure 18), but there was no visual damage to the other components of the heat source.

The test specimen was impacted in a turnaround mode using the Sandia sled test facility on December 19, 1969. The test parameters at impact were:

1. Target material - black Escondido granite;
2. Orientation - test specimen principle axis at 45 degrees to the target face and the velocity vector (Figure 19);
3. Velocity - 327 feet per second; and
4. Estimated temperature - 2070°F strength member.

The capsule was contained by the catch box following impact. Visual examination disclosed considerable capsule distortion (Figure 20). The clad was breached in the impact face and circumferentially at the midsection where a thermocouple had been during the HEAT facility test (Figure 21). There was no detectable radioactive contamination on the capsule surface following impact. The capsule was returned to AI where postmortem is in process. Preliminary observations by AI are:

1. There was a crack in the strength member and liner behind the clad crack in the impact face,

2. The SSCS discs were severely fractured, and
3. The PRD was distorted and approximately 1/8 inch of the end was sheared off.

The PRD will be returned to TRW for postmortem. The SSCS material will be returned to LASL for postmortem. AI will perform chemical and metallographic analysis of the liner and strength member.

AIT8-5 -- The test specimen was a heat source assembly similar to the current Transit flight heat source design except: (1) the capsule was identical to AIT8-1 (except platinum/20 percent rhodium clad was used), (2) the outer heat shield was made from ATJ graphite, and (3) the inner heat shield was omitted.

The test specimen was impacted in a turnaround mode on November 26, 1969, using the Sandia sled test facility. The test parameters at impact were:

1. Target material - black Escondido granite;
2. Orientation - test specimen principle axis at 45 degrees to the target face and the velocity vector (Figure 22);
3. Velocity - 335 feet per second; and
4. Estimated temperatures - 2070°F clad, midpoint
2095°F clad, impact end
2100°F strength member.

The capsule was contained by the catch box following impact. Visual examination disclosed considerable capsule distortion (Figure 23) and three or four fine cracks in the clad (Figure 24). The capsule was returned to AI where postmortem is in process. Preliminary observations by AI are:

1. The cracks in the clad have the character of a brittle type failure,
2. The strength member was leak tight when checked with helium,
3. The strength member and liner materials appear to be ductile, and
4. The PRD body was cracked.

Figure 17. AIT8-4 preheat for HEAT facility test

Do9-16035

Figure 18. AIT8-4 capsule after HEAT facility test

Figure 19. AIT8-4 test setup

D70-10727

Figure 20. AIT8-4 specimen after impact

D70-10726

Figure 21. AIT8-4 specimen after impact showing
breached clad

Figure 22. AIT8-5 test setup

D69-15618

Figure 23. AIT8-5 specimen after impact

D69-15619

Figure 24. AIT8-5 specimen after impact showing cracks in impact face

The PRD was returned to TRW for postmortem. No postmortem work is to be performed on the fuel simulant. The liner and strength member are undergoing chemical and metallographic analysis at AI.

Summary Table -- Table II summarizes the Task 8 impact test series.

TABLE II
Task 8 Impact Test Summary

Test Item Number	Clad	Strength Member	Liner	Fuel Simulant	Heat Shield	Impact Velocity (fps)	Strength Member Temperature (°F)	Impact Attitude (deg)	Impact Media
AIT8-1	Pt/10Rh	T-111	Ta-10W	Microsphere	None	353	2090	45	Granite
AIT8-2	Pt/10Rh	T-111	Ta-10W	SSC	None	385	2150	45	Granite
AIT8-3	Pt/10Rh	T-111	Ta-10W	SSC	ATJ	387	2106	45	Granite
AIT8-4	Pt/20Rh	T-111	Ta-10W	SSC	AXM-5Q pyrolytic	327	2070	45	Granite
AIT8-5	Pt/20RH	T-111	Ta-10W	Microsphere	ATJ	335	2100	45	Granite

Solid Propellant Burn Tests (F. L. Baker)

Work is continuing on the solid propellant burn tests. The principal objectives of these burn tests are to:

1. Develop suitable instrumentation for measuring the heat flux;
2. Select instrumentation for measuring flame temperature;
3. Gain experience in handling, igniting, and testing solid propellants; and
4. Characterize the thermal environment of burning solid propellant.

Ten burn tests have been conducted at Sandia on solid propellant samples (Table III).

TABLE III
Solid Propellant Burn Tests

<u>Fuel Type</u>	<u>Configuration</u>	<u>Number of Tests</u>	<u>Instrumentation</u>
UTP3001	Annular cylinder	2	Ring type slug calorimeter (Figure 25) Cylinder calorimeter Pyrometric photography
UTP3001	Solid cylinder	2	Heat flux gage (Figure 26) Pyrometric photography
Algol IIB (ANP-2872)	Solid cylinder	1	Heat flux gage Pyrometric photography
Algol IIB (ANP-2872)	Annular cylinder	1	Ring type slug calorimeter Cylinder calorimeter Pyrometric photography
Castor II (TP-H7036)	Solid cylinder	1	Heat flux gage Pyrometric photography
Castor II (TP-H7036)	Annular cylinder	1	Ring type slug calorimeter Cylinder calorimeter Pyrometric photography
Antares II	8-inch cube with 2-inch diameter hole	1	Ring type slug calorimeter Pyrometric photography Cylinder calorimeter
FW-45 (3096A)	Annular cylinder	1	Ring type slug calorimeter Pyrometric photography Cylinder calorimeter

Figure 25. Ring type slug calorimeter

Figure 26. Heat flux gage

The initial design of the heat flux gage failed to perform properly. Noise problems encountered, due to the gas ionization and the sensitivity of the recording equipment at the low output from the thermocouples, made the data unreadable. The heat flux gage was redesigned in an effort to reduce the noise level and to increase the output. The button which sees the radiation was increased in size. The thermocouples were changed to ungrounded stainless steel sheathed chromel/constantan. A less sensitive drag-pen type recorder was used. These changes to the heat flux gage and the use of less sensitive recording equipment resulted in readable and usable data.

Pyrometric photography was employed in all the tests except the first one. Data from all tests, with the exception of test No. 9, were good. Pyrometric photography data for tests 5, 6, 7, 8, and 10 are shown in Figures 27, 28, 29, 30, and 31, respectively.

Figure 27. Pyrometric photography data for test 5
(Algol IIB annular cylinder)

NOTE: Temperature area approximately
21 to 36 inches above the
propellant

Figure 28. Pyrometric photography data for test 6
(Castor II TP-H7036 annular cylinder)

NOTE: Temperature area approximately 30 inches above the propellant

Figure 29. Pyrometric photography data for test 7 (Antares II (259-B3) cubed with 2-inch diameter hole)

NOTE: Temperature area from approximately 21 to 36 inches above the propellant

Figure 30. Pyrometric photography data for test 8 (FW-4S-3096A annular cylinder)

NOTE: Temperature area from approximately 7 to 20 inches above the propellant surface

Figure 31. Pyrometric photography data for test 10 (Castor II TP-H7036 solid cylinder)

Preliminary work on the thermal model was performed by the Heat Transfer Division. The test data are being compared to the theoretical model. At this time, the available data tend to support the thermal model; however, additional testing is needed to give a complete picture. Additional data are needed for the flat burns. In addition, a series of bomb calorimeter tests is planned to measure the total heat released from the burning propellant.

Aerodynamic and Trajectory Analyses (H. R. Spahr)

Aerodynamic models of the TRW Systems Transit heat source were developed to define the crossflow hypersonic ballistic coefficient as a function of altitude for three different heat source weights. The three weights correspond to three capsule strength members of different materials and thicknesses. Trajectories for these three configurations of the TRW Transit heat source, reentering crosswise, were computed for orbital decay and a high heating rate launch abort.

These trajectories were transmitted to TRW as input data for the comparative study of the TRW Transit heat source and the Isotopes Pioneer heat source. These analyses were documented in a letter from H. R. Spahr, Sandia Laboratories, to T. H. Smith, TRW, dated October 30, 1969.

Initial Reentry Conditions for Transit Heat Source (H. R. Spahr)

Comments on trajectory initial conditions being used by TRW for the Transit heat source reentry analysis were prepared at the request of the Sandia Isotope Projects Division. The comments are documented in a memo from H. R. Spahr, 9513, to S. McAlees, Jr., 9513, dated December 3, 1969.

Heat Shield Ablation Analysis (D. W. Larson)

One-dimensional ablation models of the Transit heat shield and an ATJ graphite cylindrical block were constructed for use with the Charring Material Ablation (CMA) computer code. Several ablation runs were then made with the code in support of the Transit heat source tests in the Sandia HEAT facility. Ablation and temperature results are shown in Table IV.

TABLE IV

Results of Transit Heat
Shield Ablation Analysis

Condition	Material	Radius (in.)	Ablation (in.)	Peak Temperature (°F)
1. Calibration model; forced heat coefficient; 630 sec HEAT test; no pressure buildup	ATJ	2.219	0.091	3782
2. Same as 1, with forced enthalpy	ATJ	2.219	0.155	3782
3. Transit heat shield; forced heat coefficient; 630 sec HEAT test; no pressure buildup	Poco	2.3125	0.094	3922
4. Transit heat shield; forced enthalpy; 410 sec HEAT test; no pressure buildup	Poco	2.3125	0.129	3904
5. Same as 4, with 185 sec pressure buildup to 1.0 atmosphere at end of HEAT pulse	Poco	2.3125	0.130	2904
6. Transit heat shield; orbital decay	Poco	2.3125	0.175	4184

Investigations Involving Transit Heat Source (R. D. Klett)

Aerothermal Comparison of the Atomics International and Isotopes Capsule Technologies -- A proposal was made to compare the thermal responses of the AI/T-111 and the Isotopes/TZM capsules in the Transit and Pioneer heat sources. The purpose of the study was to determine:

1. Which technology is the most efficient and safest for each RTG and mission,
2. If one capsule technology can be used efficiently for both RTG's,
3. If either capsule technology provides a more favorable environment for the SSC fuel, and
4. Temperatures for all credible phases of each mission for inputs for the material compatibility, oxidation, and impact studies in the technology programs.

It was proposed that Sandia provide all trajectories, heating rates, and material properties to eliminate these variables from the study. TRW was directed to conduct the study for the Transit mission. Sandia will furnish the inputs to the study as proposed.

Additional investigations involving the Transit heat source are discussed in the Safety Technology Section of this report under Flight Test Studies, Reentry Simulation.

PIONEER/VIKING

Isotopes Capsules Comparative Tests (R. C. Cranfill)

Five Isotopes capsules were impact tested using the Sandia sled track facility. Table V defines the configurations tested and the test conditions.

TABLE V
Configurations Tested and Test Conditions

Test Item Number	Strength Member	Liner	Fuel Simulant	Heat Shield	Velocity (ft/sec)	Temperature (°F)	Attitude (deg)	Impact Media
1	TZM	TZM	SSC*	Yes	368	≈2105**	45	Granite
2	TZM	Ta-10W	SSC	No	357	≈2020**	45	Granite
3	TZM	Ta-10W	μspheres	Yes	328	≈2150**	45	Granite
4	TZM	Ta-10W	SSC	Yes	358	≈2050**	45	Granite
5	TZM	Ta-10W	SSC	Yes	315	≈2050**	45	Granite
*This unit contained Solid Solution Cermet (SSC) simulant only in the cylindrical portion of the capsule; the hemispherical ends were filled with solid pieces of TZM.								
**Thermocouples mounted on the strength members did not function. Therefore, test item temperature is based on the temperature of the oven 3 seconds before impact, when the oven was removed. This temperature was adjusted, based on calibration data which indicate about a 20°F drop in strength member temperature on a graphite enclosed capsule and a 120°F drop with a bare capsule.								

Test item number 1 broke open at impact, and about 50 percent of the fuel simulant and the TZM hemisphere in the impact end escaped from the capsule. The opening began on the side opposite the impact point and propagated circumferentially around the capsule for approximately 325 degrees of the circumference. The break occurred about midway between the threaded joint and the impact end. A hinge was formed by the remaining wall material, and the end cap rotated away from the cylindrical section through about a 75-degree angle (Figure 32).

Figure 32. Isotopes unit number 1 after impact

Test item number 2 also broke open at impact, and approximately 30 percent of the fuel simulant was released. The break was quite similar to that experienced by the first capsule. It appeared to start in the same manner and propagated circumferentially about 240 degrees around the circumference. The primary impact deformation was larger on this capsule than on the first one, and slapdown deformation was more apparent (Figure 33). There was some opening of the threaded joint on both capsules.

Visual examination of test item number 3 indicated that it survived the impact. There were no apparent openings in the strength member. The primary deformation at impact and the slapdown deformation were more than experienced with the SSC simulant filled capsules (Figure 34).

Figure 33. Isotopes unit number 2 after impact

Figure 34. Isotopes unit number 3 after impact

Test item number 4 had a crack in the strength member. The crack was at the base of the threaded section of the female end and ran circumferentially around the capsule for about 0.5 inch. The threads of the joint had opened on the side opposite the primary impact face, and there was longitudinal motion between the capsule halves (Figure 35). No detectable fuel simulant was released from the openings.

Test item number 5 separated into two pieces at the threaded joint (Figure 36). The liner broke open along the same separation line as the strength member, and approximately 40 percent of the fuel simulant was lost.

A posttest examination of these capsules is planned, and the results will be documented as they become available.

Figure 35. Isotopes unit number 4 after impact

Figure 36. Isotopes unit number 5 after impact

RTG Data Submittal Plan (H. R. Spahr)

Review of the RTG Data Submittal Plan, prepared by the Viking/Pioneer Safety Studies Subgroup, was completed. Comments on this plan were submitted to AEC Headquarters personnel.

Multiple Orbit Reentry Comparative Ablation Analysis (S. McAlees/D. W. Larson)

An analysis was conducted to determine the ablation which would occur during orbital decay and multiple orbit reentry of the Isotopes hexagonal heat shield enclosing: (1) the AI/T-111 capsule, or (2) the Isotopes/TZM capsule. The analysis assumed a side-on-stable reentry orientation, and the ablation model was one-dimensional. A complete listing of conditions and assumptions was included in a memo to S. McAlees, 9513, dated September 16, 1969, and in a follow-up memo to J. Jacobs, 9522, dated November 5, 1969. The results of the analysis are given in Table VI. The success (or failure) margin was determined by dividing the expected ablation into the ablative material available for the condition described.

Pioneer/Viking Proposals by Isotopes (R. D. Klett)

The aerothermal sections of the Pioneer/Viking SNAP-19 proposals were reviewed. Although there are some differences in the two missions, there are many similarities and the analyses in the proposals were almost identical. As stated in the proposals, "The study is limited in scope and thus should be treated only as a preliminary survey." Because of the approximate methods and inputs used to calculate the temperatures, they should be treated as rough estimates of the actual temperatures. The tests and calculations presented in the proposals do not prove that the Isotopes intact heat source (IIHS) has a superorbital reentry capability. The calculations are not sufficiently accurate and the tests do not simulate actual conditions well enough to allow evaluation of the IIHS or to select a capsule or heat shield design.

TABLE VI
Results of Multiple Orbit Reentry Ablation Analysis

Condition/Event	Atomics International T-111 Capsule		Isotopes TZM Capsule	
	Success	Margin	Success	Margin
A Strength member + gaps + heat shield (no Pt-Rh, no insulation) (300 kft perigee)	Yes	$0.533/0.515 = 1.03$	No	$0.450/0.452 = 0.995$
B Strength member + gaps + Pt-Rh + heat shield (no insulation) (300 kft perigee)	No	$0.516/0.533 = 0.968$	No	$0.414/0.469 = 0.882$
C Strength member + gaps + Pt-Rh + 0.1 inch insulation + heat shield (300 kft perigee)	No	$0.426/0.533 = 0.800$	No	$0.324/0.469 = 0.690$
D Strength member + gap + 0.1 inch insulation + heat shield (no Pt-Rh) (300 kft perigee)	No	$0.453/0.515 = 0.879$	No	$0.370/0.452 = 0.818$
E Strength member + gaps + Pt-Rh + 0.08 inch insulator-ablator* + heat shield (300 kft perigee)	No	$0.506/0.533 = 0.949$	No	$0.404/0.469 = 0.861$
F Strength member + gap + 0.08 inch insulator- ablator* + heat shield (no Pt-Rh) (300 kft perigee)	Yes	$0.533/0.515 = 1.03$	No	$0.450/0.452 = 0.995$
A Same as A above (280 kft perigee)	Yes	$0.533/0.400 = 1.33$	Yes	$0.450/0.376 = 1.19$
B Same as B above (280 kft perigee)	Yes	$0.516/0.415 = 1.24$	Yes	$0.414/0.393 = 1.05$
C Same as C above (280 kft perigee)	Yes	$0.426/0.415 = 1.02$	No	$0.324/0.393 = 0.824$
D Same as D above (280 kft perigee)	Yes	$0.453/0.400 = 1.13$	No	$0.370/0.376 = 0.984$
E Same as E above (280 kft perigee)	Yes	$0.506/0.415 = 1.22$	Yes	$0.404/0.393 = 1.03$
F Same as F above (280 kft perigee)	Yes	$0.533/0.400 = 1.33$	Yes	$0.450/0.376 = 1.19$
<p>Both capsules will survive multiple orbit reentry from 260 kft perigee for all combinations of components.</p> <p>Both capsules will survive orbital decay for all combinations of components.</p> <p>The heat shields of both capsules will experience thermal stress failure at some level of reentry velocity (superorbital) and angle. While this boundary is difficult to estimate, it would be at approximately the same level for both systems.</p>				
*Assumes pyrolytic graphite insulation also serves as an ablator.				

ISOTOPE BRAYTON HEAT SOURCE (IBHS)

Proposed Nuclear Safety Criteria (R. G. Illing)

Work has continued on the coordination of Proposed Nuclear Safety Criteria for the IBHS, directed toward flight qualified units.

Several items peculiar to the Isotope Brayton Power System complicate the nuclear safety considerations of the system. The system will require the largest amount of radioactive fuel ever assembled for one radioisotope space power device, approximately 45 kilograms to produce 25 kilowatts. In addition, ground tests will be conducted at the NASA/Lewis Research Center Space Power Facility at Plum Brook, near Sandusky, Ohio. The ground tests are expected to employ nuclear fuel. The safety criteria being developed will consider both of these factors. However, minimum Radiological Safety Criteria for use on the Isotope Brayton Ground Test Program were provided to NASA/Lewis Research Center by AEC/Albuquerque Operations Office.

Operational Temperature Thermal Analysis (D. W. Larson)

An analysis was conducted to determine the feasibility of using Transit heat source capsules for the IBHS. Steady-state calculations indicated that with a 1670°F uniform temperature heat exchanger, the liner temperature of a fully fueled Transit capsule on the heat source would exceed 2000°F.

Radiation Configuration Factors (D. W. Larson)

The radiative view factors for a two-dimensional thermal model of the IBHS were determined. The 40 required view factors were determined by using the CONFAC II computer code. The code was also used to evaluate radiative view factors to the heat source heat exchanger for five different tentative capsule heat shield designs.

Superorbital Velocity Reentry Protection Requirements (D. W. Larson)

A study was conducted for the Sandia Space Power Systems Division which indicated the approximate expected ablation of an IBHS capsule during superorbital velocity reentry. The study summarized the results

of other superorbital reentry analyses, both for prompt reentry and multiple orbit reentry. Based on the analyses of earlier systems, approximately 0.5 inch of ablation material would prevent an ablation failure for most reentry conditions. There were no reentry analyses conducted, however, of any particular IBHS design.

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY

Alpha Deposition in Cermets (C. J. M. Northrup, Jr.)

(Also see Tensile Response of Alpha Irradiated Molybdenum on page 57 of this report.)

The distribution functions for thermalized alphas emitted from radioisotopes have been the subject of a number of investigations.¹⁻⁵ The alphas injected by the radioactive ceramic particles into the molybdenum matrix of a cermet fuel may alter the metal web's physical properties. Therefore, calculations were made to correlate: (1) dose of alpha particles, (2) time from fabrication, (3) distance into the molybdenum matrix, and (4) size of the radioactive ceramic particle. These calculations subsequently were used to simulate various ages of cermets by injecting equivalent alpha doses into molybdenum using the 90-inch cyclotron at the Lawrence Radiation Laboratory. Although the molybdenum matrix in the current fuel form is only several micrometers thick, the general solution for thermalized alphas will be computed.

The flux of thermalized alphas being deposited in the molybdenum coating of a plutonia particle can be determined in the following manner. The quantity n is defined as the number of thermalized alphas per unit time per unit volume of molybdenum, and n_0 is the number of alphas generated per unit time per unit volume of plutonia. The following simplifying assumptions are made:

1. The ceramic radioactive particles are homogeneous, isotopic spheres, and the molybdenum coating is a homogeneous, isotopic film with thickness greater than the range of the alphas in molybdenum;
2. The emitted alphas travel in a straight line; and
3. The range R of the emitted alphas is the same in plutonia and molybdenum.

Assumption (1) is dependent on the quality of the fuel particle and the molybdenum coating. Assumption (2) is adequately fulfilled for

alphas with energies of 5.5 MeV or less. The range of 5.5 MeV alphas in plutonia is probably between 12.4 and 13.6 μm versus approximately 12.7 μm in molybdenum.^{6,7} The Bragg-Kleeman rule indicates that the relative error will be small for alphas with energies below 5.5 MeV.⁸

Consider a spherical plutonia particle with radius r embedded in an infinite molybdenum matrix (Figure 37). The alphas being thermalized in the vicinity dv of point P , a distance x away from the surface of the radioactive particle, originate in the spherical segment $2\pi Rh\Delta R$. The alphas potentially available to the vicinity of point P then equal $n_o(2\pi Rh\Delta R)$. For each alpha that can reach P , a rectangular volume element $(\Delta R)^3$ exists about P for which the capture probability for the alpha is

$$\frac{(\Delta R)^2}{4\pi R^2}.$$

For any given P , the intersection of all of such volume elements contain P as a surface element. The number of thermalized alphas per unit volume per unit time is constant in this region and equals

$$\frac{n_o(2\pi Rh\Delta R)}{(\Delta R)^3} \frac{(\Delta R)^2}{4\pi R^2}.$$

Thus, the number of alphas per unit volume per unit time at P equals

$$n = \frac{n_o(2\pi Rh\Delta R)}{(\Delta R)^3} \frac{(\Delta R)^2}{4\pi R^2} = \frac{n_o h}{2R}.$$

Figure 37.

Plutonia sphere embedded in infinite molybdenum matrix

Since

$$R = h + d + x$$

$$R^2 = L^2 + (x + d)^2$$

and

$$r^2 = L^2 + (r - d)^2,$$

then

$$\begin{aligned} R^2 &= (x + d)^2 + r^2 - (r - d)^2 = \\ &= x^2 + 2xd + d^2 + r^2 - r^2 + 2rd - d^2, \end{aligned}$$

that is,

$$R^2 = x^2 + d(2x + 2r) \quad \text{or} \quad d = \frac{R^2 - x^2}{2(r + x)}.$$

Finally,

$$h = R - x - \frac{(R^2 - x^2)}{2(r + x)}.$$

and

$$n = \frac{n_o}{2R} \left(R - x - \frac{(R^2 - x^2)}{2(r + x)} \right).$$

Taking

$$R = 13.25 \mu\text{m},$$

$$n_o = 4.48 \times 10^{12} \text{ alpha/sec/cc (12.1 Ci/gm and 10 gm/cc).}$$

Figure 38 gives the thermalized alpha dose in molybdenum as a function of distance for $^{238}\text{PuO}_2$ fuel particles of several radii.

x (μm)	r (μm)					
	5	10	20	50	100	150
0	0	0.76	1.50	1.94	2.09	2.14
1	0	0.73	1.37	1.78	1.92	1.97
2	0	0.69	1.24	1.62	1.76	1.81
3	0	0.65	1.12	1.47	1.60	1.64
4	0.07	0.60	1.00	1.31	1.43	1.48
5	0.12	0.55	0.89	1.16	1.27	1.31
6	0.15	0.49	0.77	1.02	1.11	1.15
7	0.17	0.43	0.66	0.87	0.96	0.99
8	0.16	0.36	0.55	0.72	0.80	0.83
9	0.15	0.30	0.44	0.58	0.65	0.67
10	0.12	0.23	0.34	0.44	0.49	0.51
11	0.09	0.16	0.23	0.30	0.34	0.35
12	0.05	0.09	0.13	0.17	0.19	0.19
13	0.01	0.02	0.03	0.03	0.04	0.40

Figure 38. Thermalized alpha dose in molybdenum as a function of distance for $^{238}\text{PuO}_2$ fuel particles of several radii

References

1. I. Chudacek, "Energy Spectrum of Alpha Particles from Sources of Different Thicknesses," *Czec. Journ. Phys.*, 8, 396 (1958).
2. W. L. Holley, Methods of Assessing the Lung Dose from Inhaled $^{238}\text{PuO}_2$, SC-TM-67-594, Sandia Laboratories, Albuquerque, New Mexico, July 1967.
3. C. J. M. Northrup, Jr., and D. E. Amos, HECON Computations for the Diffusion of Helium in Alpha-Emitting Isotopes, SC-RR-69-103, Sandia Laboratories, Albuquerque, New Mexico, May 1969.
4. C. J. Kershner, Mound Laboratory Isotopic Power Fuels Programs, April-June 1969 (U), MLM-1607, July 31, 1969 (CRD).
5. C. J. Kershner, Mound Laboratory Isotopic Power Fuels Programs, July-September 1969 (U), MLM-1610, October 31, 1969 (CRD).
6. C. F. Williamson, J. P. Boujot, and J. Picard, CEA-R-3042.
7. G. N. Huffman, Mound Laboratory Isotopic Power Fuels Programs, January-March 1969 (U), MLM-1604, April 30, 1969 (CRD)
8. R. D. Evans, The Atomic Nucleus, McGraw-Hall, New York, New York, 652, 1967.

Tensile Response of Alpha Irradiated Molybdenum (R. L. Buckner/ C. J. M. Northrup, Jr./R. P. Wemple)

Molybdenum wires approximately 100 micrometers in diameter were exposed to 4.8 MeV alpha particles produced by the 90 inch cyclotron at Lawrence Radiation Laboratory. Alpha doses simulating $^{238}\text{PuO}_2$ cermet fuels 1 to 5 years old were deposited in a band approximately 1 micrometer thick. In an actual cermet, the damage zone could extend into the molybdenum approximately 13 micrometers from each plutonia surface if the molybdenum matrix were this thick. The band of thermalized alpha particles produced on the test specimens was obtained by rotating

the specimen in the cyclotron's beam while maintaining a constant particle energy (Figure 39). Irradiation was carried out in a vacuum at liquid nitrogen temperatures. This ensured that thermal embrittlement could be neglected.

Figure 39. Irradiation technique

Initial room temperature tensile tests on wires exposed to 5-year simulants indicated that the ultimate strength increased by approximately 3 percent while the percent elongation was reduced about 40 percent. Because the damage zone constitutes only approximately 2 percent of the volume of the wire, these tests indicate significant embrittlement has occurred.

Alpha Radiation Damage in Molybdenum (G. J. Thomas/C. R. Hill/
C. J. M. Northrup, Jr./R. P. Wemple)

Commercially procured discs of molybdenum foil 127 micrometers thick were irradiated on a Commonwealth Scientific Ion Thinner (5 keV nominal) at Sandia and the 90-inch cyclotron (4.8 MeV) at Lawrence Radiation Laboratory. Table VII lists the impurities revealed by chemical analysis in three different anneals of the same foil.

TABLE VII
Results of Chemical Analysis

<u>Impurity</u>	<u>Small Grain</u>	<u>Medium Grain</u>	<u>Larger Grain</u>
Oxygen (O ₂)	300 ± 50 ppm	250 ± 50 ppm	< 100 ppm
Calcium	10 - 100 ppm	10 - 100 ppm	10 - 100 ppm
Magnesium	< 10 ppm	< 10 ppm	< 10 ppm
Manganese	ND < 10 ppm	≈ 10 ppm	ND < 10 ppm
Iron	10 - 100 ppm	10 - 100 ppm	10 - 100 ppm
Copper	10 - 100 ppm	10 - 100 ppm	10 - 100 ppm
Sodium	< 10 ppm	< 10 ppm	< 10 ppm
Carbon	< 0.01%	< 0.01%	< 0.01%

Three different grain sizes were obtained from the same foil in the following manner:

1. Small Grain - The as-received foils had a large variation in grain size. Many of the grains were small, and an examination showed a high dislocation density (Figure 40).
2. Medium Grain - The foil was vacuum annealed at 1020°C for 1 minute. Considerable grain growth was evident. A reduction in the dislocation density occurred, and the chemical analysis also suggested a reduction in the oxygen content (Figure 41).
3. Large Grain - The foil was vacuum annealed at 1500°C for 10 minutes. Further grain growth took place, the oxygen concentration was further reduced, and the grains were relatively free of dislocations. Annealing for up to 45 minutes at this temperature did not appear to change the grain size or dislocation density from a 5 minute anneal, and, therefore, a period of 10 minutes was used to prepare the specimens for irradiation (Figure 42).

Figure 40. Small grain molybdenum foil
as received (20,000X)

Figure 41. Medium grain molybdenum foil after annealing 1 minute at 1020°C (42,000X)

Figure 42. Large grain molybdenum foil after annealing for 45 minutes at 1500°C (5000X)

All anneals were conducted in a Brew Furnace at 10^{-6} torr using a 6000°C/min temperature ramp.

The 90-inch cyclotron was modified to produce 4.8 MeV alphas. The energy determination was obtained by scattering the cyclotron beam with a thin aluminum foil and then comparing the energies of the scattered beam with ^{244}Cm and ^{238}Pu alpha particle standards. An Ortec solid state detector with an 800 channel analyzer provided a direct read-out of the alpha energies.

During actual operation, the cyclotron beam was swept over the specimens to ensure homogeneous irradiation. The homogeneity was checked periodically by inserting a lithium iodide crystal and visually checking the density distribution of the F-centers. The accuracy of the dosimetry was enhanced by using a floating, reverse bias between the sample chamber and a guard ring. Both liquid nitrogen and room temperature irradiations were conducted on samples having various grain sizes.

The Commonwealth Scientific Ion Thinner was used as an ion source to irradiate previously thinned, large grain specimens with a dose of approximately 5×10^{17} ion/cc. Irradiations were conducted at approximately room temperature. The samples were examined with a Phillips (100 keV) E M-200 transmission electron microscope. Figure 43 shows the damage resulting from the alpha irradiation. After a 10 minute anneal at 900°C (Figure 44) most of the damage remained; however, some of the lattice strain was relieved, as evidenced by the higher resolution of the defect clusters. The detailed structure of the defects has not been analyzed. Ten minutes at 1200°C annealed the defect clusters (Figure 45), but resulted in a markedly increased dislocation density as compared with the unirradiated foil. In addition, circular defects resembling gas bubbles were produced.

Figure 43. Alpha radiation damage to thinned, large grain molybdenum foil from dose of $\sim 5 \times 10^{17}$ ion/cc (80,000X)

Figure 44. Alpha radiation damage in molybdenum foil after annealing at 900°C for 10 minutes ($\approx 35,000$ to $40,000\times$)

Figure 45. Alpha radiation damage in molybdenum foil after annealing at 1200°C for 10 minutes ($\approx 35,000$ to $40,000\times$); the wavy lines are probably moiré fringes (from oxide?)

Reentry Ablation Testing in a Hyperthermal Arc Tunnel
(I. B. White)

Two LASL-fabricated ThO_2 specimens were exposed to simulated reentry heat fluxes in the Sandia 40-kW arc tunnel. The specimens were cylindrical in shape and were approximately 0.316 inch in diameter by 0.345 inch long. Their densities were 8.66 g/cc. The theoretical density of ThO_2 is 9.69 g/cc.

Both specimens were preheated to 1850°F and then immediately inserted into the plasma. Specimen 12748 was exposed to a heat flux of 87 Btu/ft^{3/2}-sec., and specimen 12749 was exposed to a heat flux of 72 Btu/ft^{3/2}-sec. The exposure time for each specimen was 30 seconds. Neither specimen experienced any melt, ablation, or thermal fragmentation during the tests. However, posttest microphotographs did reveal numerous small cracks around the circumference of the specimens.

The fact that fragmentation did not occur in these specimens is in direct contrast to the results obtained from previous tests of two similar ThO_2 specimens at these same reentry conditions. Specimens 12746 and 12747 began to fragment immediately upon exposure. Sixty-five percent of specimen 12746 was sheared away during the 30-second exposure, and specimen 12747 was completely fragmented within 1 second.

The difference in the behavior of the preheated and nonpreheated specimens indicates that preheating (in an isotopic generator due to the operating temperature) reduces the effects of thermal stress on fuels. Further testing of preheated and nonpreheated specimens at various test conditions and levels of preheating is planned, along with theoretical investigations.

Similarity Analysis (R. E. D. Stewart/F. C. Wessling)

A similarity analysis was performed to determine the nondimensional similarity parameters which govern the temperature and thermal stress distributions in a finite right circular cylinder heated from one end. This is essentially the situation that exists when a cylindrical specimen is heated end-on in a plasma arc tunnel. The results of the analysis enable one to correlate test results from different specimen sizes, materials, and/or heating signatures, provided the

relevant material properties are known and provided the tests are properly scaled so as to provide similarity. The results also indicate the relative importance of the various material properties and the accuracy with which each must be known in order to predict temperatures and thermal stresses with a given accuracy.

The analysis, however, was based on the assumption of constant material properties. In view of this assumption, the question immediately arises as to the relevance of the results to actual test situations involving real materials. This question is currently being investigated by comparing computer results using temperature and strain dependent properties with results obtained from the constant property model. Some thermal shock tests are also scheduled on zirconium dioxide specimens in the Sandia plasma HEAT facility to provide a check on theoretically predicted failure times.

The possibility of generalizing the similarity analysis to the case of nonconstant properties is also being investigated. Unfortunately, one of the material properties relevant to thermal shock problems, Young's Modulus, depends not only on temperature but also on strain. This is particularly true at elevated temperatures. It is feared that a similarity analysis which fully accounts for temperature and strain dependent properties may result in a set of similarity requirements so restrictive that they can never be met in practice. Thus, the results of a more accurate analysis may actually prove to be of less practical value than those of the constant property model.

The computer program used to calculate the temperature and thermal stress distributions is being modified considerably to increase its flexibility and general usefulness. A routine is being built in to generate a suitable finite element mesh based on a minimum amount of input information. At present, the mesh must be generated separately and supplied as input. Modifications are also being made to allow specification of output directly in the form of plots of the nondimensional similarity parameters of interest. At present, the program simply prints out the real temperature and stress distributions at specified time intervals.

FLIGHT TEST STUDIES

Reentry Simulation (A. C. Bustamante)

A payload feasibility and optimization study was conducted for a flight test of a Transit heat source using an Athena vehicle. The study considered the following payloads:

1. Various RV configurations with different numbers of heat sources;
2. Heat sources only, instrumented and noninstrumented; and
3. Various scaled heat sources and different numbers of heat sources.

Ballistic parameters and stability characteristics were determined for the above payloads. Some of the proposed payload configurations are shown in Figure 46.

<u>CONFIGURATION</u>	<u>WEIGHT (Lbs)</u>	<u>BALLISTIC PARAMETER (Lbs/Ft²)</u>
$\theta_F = 14^\circ 2'$	193	125
$\theta = 26 \text{ } 34'$	80	34
105	80 SIDE-ON 118 TUMBLING (EOE)
354	120 SIDE-ON 177 TUMBLING (EOE)
205	100 SIDE-ON 147 TUMBLING (EOE)
TRANSIT HEAT SOURCE	13	40 SIDE-ON 57 END-ON 55 TUMBLING (EOE)
D69-13785		

Figure 46. Proposed payload configurations

A program schedule was developed which defines the goals and objectives that must be met if an Athena flight test is to be conducted in support of the Transit program. This schedule is shown in Figure 47.

Figure 47. Athena/Transit flight test schedule

INTACT HEAT SOURCE

Response of Structures Constructed of Plastically Anisotropic Materials (T. A. Duffey)

In an actual fuel capsule, the outer shell material is generally in a state of biaxial stress. Since material properties for biaxial stress states in the plastic regime are extremely difficult to obtain, it is common, and generally valid, to arbitrarily extend uniaxial material data to a biaxial state of stress using an isotropic plastic yield

condition such as that due to von Mises' law. It is now known that certain materials, notably certain alloys of titanium, may exhibit a phenomenon termed "texture hardening," in which the material is in an initial plastically anisotropic state. The result is that biaxial yielding may no longer be adequately predicted by extending uniaxial data according to von Mises' law, for instance.

An investigation is underway to evaluate some possible errors in calculated transient structural response which may result if uniaxial material data are arbitrarily extended (say by von Mises' law) to the biaxial situation without qualitative biaxial information on the material. Toward this end, a long cylinder undergoing biaxial stress subjected to impulsive pressure loading was analyzed. Comparisons between transient deflections for plastically anisotropic and isotropic materials indicate differences as large as 25 percent, even when uniaxial material properties are identical along the principal directions in the cylinder reference surface.

DOSE MODEL

Radiation Risk Criterion (M. A. Parsont)

Copies of "A Recommended Radiation Risk Criterion for SNAP Systems" were circulated to members of the AEC Division of Biology and Medicine, several contractors, and AEC/SNS personnel for comments. This is a continuation of the development of a Radiation Risk Criterion which will be applicable to all SNAP systems and with which a contractor could judge the biological safety of his system.

ABORT MODEL

Leak Detection (J. L. Entrekin)

An investigation is underway to determine whether or not particle detectors in a laminar flow cleanroom background are useful for detecting leaks in impacted RTG heat source fuel capsules. The technique consists of putting the impacted capsule in a cleanroom environment, pumping smoke or other fine particles into the capsule under low pressure and sampling the air around the capsule with a particle photometer

or other detection device. Once a crack or leak is found, equipment of greater precision is used to determine quantitative damage.

For the two experiments performed thus far, a capsule was fabricated and a 0.0005-inch thick shim with a small notch cut in it was placed between the mating surfaces of the capsule halves. In the first experiment, the notch measured 0.0005-inch wide by 0.750-inch long, and in the second experiment, the notch measured 0.0005-inch wide by 0.040-inch long. A cigarette smoke generator provided small particles which were pumped into the capsule at approximately 5 psig. A Sinclair-Phoenix particle photometer was used as the detection device, and it was set to sample the air at 1 cubic foot per minute. The leak was easily found in the first experiment, and the detector indicated a leak rate of approximately 10^{11} particles per cubic foot of air samples. The indicated leak rate for the second experiment was 10^6 particles per cubic foot of air sample, but the indication was not as positive as would be desirable for checking actual fuel capsules. In the future, better test equipment will be fabricated and conditions for the experiments will be controlled more exactly in order to determine the actual performance capabilities of the system.

Scaling Laws for Fuel Capsules Subjected to Blast, Impact, and Thermal Loading (T. A. Duffey)

Fuel capsules may be subjected to blast, fragment impact, earth impact, and thermal loading. Capsules must be designed to withstand these loadings so that radioactive fuels remain contained by the capsules; they must be tested to determine if the design criteria have been met.

It may not be feasible to test a full scale capsule, both from safety and economic standpoints. In such cases, it would be highly desirable to construct a scale model for testing and then deduce the response of the prototype capsule from the model response. However, geometrical scaling alone may not be entirely suitable since material cost and hazards may still be appreciable. Testing with models constructed of less expensive or dangerous materials is thus appropriate, if the response of the model can be shown to be representative of prototype fuel capsule response.

An effort is underway to determine structural scaling laws for application to fuel capsules subjected to blast, impact, and thermal loading. Both similar and dissimilar modeling techniques are being taken into consideration. Problem areas for both scaling techniques will be isolated.

Fuel Disc Earth Impact Simulation Techniques (T. A. Duffey)

Should a fuel capsule containing solid radioactive fuel discs be exposed to a severe environment, such as blast or reentry heating, it is possible that a disc could escape from its container and impact on earth. It is essential, from a safety standpoint, to assure that particles of fuel resulting from impact remain larger than a certain critical diameter. Since the fuel disc actually is an aggregate of coated particles, an accurate analytical or numerical prediction of particle breakup is extremely unlikely. Consequently, it is necessary to resort to impact testing for particle size data. Due to the health hazard, it is not permissible to impact an uncontained fuel disc on the earth. As a result, earth impact must be simulated in such a manner that fuel particles are safely contained following impact.

At present, two impact simulation techniques are used to approximate earth impact. In the first scheme the fuel disc is placed on the back surface of a containment capsule. The capsule and disc are accelerated from rest and then impacted on a stationary target at some velocity. Following capsule-target impact, the unrestrained fuel disc continues to move at constant velocity until it impacts the front surface of the containment capsule.

In the second scheme, the target is propelled into the containment capsule. In this case, the disc is initially in contact with the inside front surface of the containment capsule.

Both simulation techniques were analyzed with a one-dimensional strain model. A linear elastic constitutive relation and simple graphical constructions were utilized to crudely examine the first few stress wave-interface interactions in each of the two impact simulation schemes. It was shown that both schemes are equally valid simulations for the special case in which impedances of target and containment materials

are identical. For unequal impedances, however, it was shown that only the first technique is valid. The analysis will be documented in a report.

Emissivity Switch (D. W. Larson)

An analysis was conducted to determine the effect of changing the emissivity in a radiation gap of an RTG heat source during atmospheric reentry. The Transit heat source was used in the study since it contains a radiation gap behind the outer graphite heat shield. The results indicated that an emissivity switch would reduce peak internal temperatures considerably for some superorbital velocity reentries. The complete results of the analysis are contained in a memo to S. McAlees, 9513, dated September 29, 1969.

Thermal and Stress Analysis Code (D. W. Larson)

A two-dimensional thermal model with directional dependent thermal conductivity was constructed and used to check the thermal section of a combined thermal and stress analysis code being developed by J. H. Biffle, 1542.

Thermal Conductivity Tests of Carbitex-500 (R. D. Klett)

The Sandia thermal conductivity tests of Carbitex-500 perpendicular to the laminates were completed. The tests were conducted from 1000° to 3400°F, which are the limits of the facility. Test samples are ready for conductivity tests at Union Carbide/Parma. The tests will be run parallel and perpendicular to the laminates from 2200° to 5000°F.

The Sandia test data were supplemented by data from Martin, Southern Research, Parma, and Battelle tests, but only limited and conflicting data are available at reentry temperatures. Extrapolating the more numerous low temperature data that are in good agreement would result in at least a factor of 2 error at 5000°F. Therefore, the data will not be released until the Parma tests have been completed.

Aerodynamic Drag Analysis (D. E. Randall)

The aerodynamic drag analysis of the 2-inch diameter configuration was completed. The ballistic coefficients for three flow regimes and three types of motion are given in Table VIII.

TABLE VIII
Ballistic Coefficients

Type of Motion	Free Molecule	Continuum Hypersonic	Continuum Subsonic $Re < 3 \times 10^5$	Continuum Subsonic $Re > 4 \times 10^5$
Face-on	5.513	6.96	9.76	9.76
Tumbling	8.02	14.77	20.31	22.34
Edge-on	43.41	74.14	77.14	302.8

These characteristics result in peak orbital decay heating rates of 59 Btu/ft²-sec and 84 Btu/ft²-sec for the face-on and tumbling modes of motion, respectively. Impact velocities for the same cases are estimated to be 90 and 131 fps. Reentries resulting from aborts of the Saturn launch vehicle fourth stage injection burn are being studied. A three-dimensional thermal model utilizing the CINDA program is in preparation.

Multiple Revolution Reentry Meeting (S. McAlees/H. R. Spahr)

Representatives from the Sandia Reentry and Space Sciences Division met with representatives from NASA, Isotopes, GE, and TRW Systems at NASA/Ames on November 6, 1969, to discuss the multiple revolution reentry problem. Topics discussed included:

1. Solar and lunar effects on the multiple revolution reentry problem,
2. Heat source attitude stability during the multiple revolution reentry, and
3. Hyperbolic velocity multiple revolution reentry.

COMPUTER CODES

Douglas Arbitrary Body Computer Code On-Line Graphics Capability (H. R. Spahr)

The Douglas Arbitrary Body Computer code calculates the aerodynamic coefficients of complex, unshielded configurations for free-molecule and continuum supersonic and hypersonic flow. A motion picture describing this code was shown to the Sandia Computer-Aided Design Systems Division. A literature search has been started for documentation of an on-line graphics version of this code, compatible with Sandia Laboratories computers.

SIRNETCO (H. R. Spahr)

The Sandia Laboratories SIRNETCO code uses modified Newtonian flow theory to calculate the aerodynamic coefficients of unshielded axisymmetric objects. The code was modified to convert it from the CDC 3600 to the CDC 6600 computer. This code is now fully operational on the CDC 6600 computer.

CONVRT (H. R. Spahr)

Computer code CONVRT, which assigns line numbers to Fortran source programs entered on the GE Mark II time-sharing service using the data storage mode, is now operational. CONVRT has been modified to be compatible with the Sandia card to ASC-II paper tape conversion routine. CONVRT is being used to make codes which are operational on the larger computers operational on the GE Mark II time-sharing service.

HRS015 (H. R. Spahr)

Computer code HRS015 calculates the hypersonic ballistic coefficients of blunt objects in the transition flow regime. This computer code is now operational on the GE 635 computer in Los Angeles, on the Mark II time-sharing service, which is accessible using the TTY in Building 892.

HRS016 (H. R. Spahr)

Computer code HRS016 numerically integrates the differential equations of motion to compute nonlifting point mass trajectories for

Tonopah Test Range drop tests or early launch aborts. This computer code is now operational on the GE 635 computer in Los Angeles, on the Mark II time-sharing service, which is accessible using the TTY in Building 892.

HRS017 (H. R. Spahr)

Computer code HRS017 uses the approximate closed form orbital decay equations to compute the trajectory and resultant reentry environment for an object undergoing multiple revolution orbital decay from an initially highly elliptical orbit. Version 3 of this code also prepares a punched card input data deck for use with the CMA ablation code.

A new source deck of version 1 of this code, with six improvements, is now operational on the QUIKTRAN remote terminal. New source decks of version 3 of this code, with the same improvements, are now operational on the CDC 3600, CDC 6600, and Univac 1108 computers.

Radiative Reentry Heating Code (D. W. Larson)

Computer code PRATRAP was received from NASA/Ames. The code determines the radiative energy transport in the viscous nonadiabatic stagnation region shock layers. The code will give Sandia the capability to predict reasonably accurate radiative heating rates to hyperbolic velocity reentry vehicles. The code is presently being checked out on the CDC 6600 and the Univac 1108 computers.

RADHTG (D. W. Larson)

Computer code RADHTG, which uses a simple correlative equation to determine the radiative and convective heating to the stagnation point of a reentering sphere, is now operational on the General Electric time-sharing computer system.

DISTRIBUTION:

TID-4500 (54th Ed.) UC-36 (177)

U. S. Atomic Energy Commission (5)
Division of Space Nuclear Systems
Space Electric Power Office
Washington, D.C. 20545
Attn: G. A. Newby
Assistant Director
G. P. Dix, Chief
Safety Branch
R. T. Carpenter, Chief
Isotope Power Sys. Branch
J. A. Powers, Chief
Isotopes Fuels and Matls. Br.
C. E. Johnson, Chief
Reactor Power Sys. Branch

U. S. Atomic Energy Commission
Space Nuclear Propulsion Office
Washington, D.C. 20545
Attn: R. S. Decker, Jr., Chief
Safety Branch

U. S. Atomic Energy Commission
Division of Isotope Development
Washington, D.C. 20545

U. S. Atomic Energy Commission (2)
Director of Regulation
Washington, D.C. 20545
Attn: C. K. Beck
Deputy Director
R. W. Klecker
Div. of Reactor Licensing

U. S. Atomic Energy Commission (2)
Division of Biology and Medicine
Washington, D.C. 20545
Attn: J. Z. Holland
Fallout Studies Branch
H. D. Bruner, Asst. Dir.
Medical and Health Research

U. S. Atomic Energy Commission
Space Nuclear Propulsion Office
Albuquerque Extension
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115
Attn: H. P. Smith

U. S. Atomic Energy Commission (2)
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115
Attn: B. W. Colston, Director
Space and Special Projects
Division
For: J. Nicks
J. F. Burke, Director
Operational Safety Div.

AEC Site Representative
National Aeronautics and Space Adm.
Manned Spacecraft Center
Houston, Texas 77058
Attn: W. C. Remini
Bldg. 16, Code ZS-5

Dr. D. W. Sherwood
National Aeronautics and Space Adm.
Manned Spacecraft Center (MSC-TD)
Houston, Texas 77058

Deputy I. G. for Insp. & Safety
USAF
Directorate of Nuclear Safety
Nuclear Power Division
Kirtland Air Force Base
New Mexico 87117

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91103
Attn: A. L. Klascius
Radiation Health and Safety

Los Alamos Scientific Laboratory (5)
P. O. Box 1663
Los Alamos, New Mexico 87544
Attn: Dr. L. D. P. King
Dr. Wright Langham
C. F. Metz, CMB-1
F. W. Schonfeld, CMF-5
J. A. Leary, CMB-11

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

DISTRIBUTION (cont):

Thomas B. Kerr
Code RNS
National Aeronautics and Space Adm.
Washington, D.C. 20545

Mr. Glenn Goodwin
National Aeronautics and Space Adm.
Ames Research Center
N-200-4
Moffett Field, California 94035

National Aeronautics and Space Adm.
Goddard Space Flight Center
Glenn Dale Road
Greenbelt, Maryland 20771
Attn: A. W. Fihelly
Nimbus Project

Naval Facilities Engineering Com.
Dept. of the Navy, Code 042
Washington, D.C. 20390

Space Nuclear Propulsion Office
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: L. Nichols

Mr. George Mandel
Information Specialist
Aerospace Safety Research and
Data Institute
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Union Carbide Corporation (2)
Nuclear Division
P. O. Box X
Oak Ridge, Tennessee 37831
Attn: R. A. Robinson
Isotope Development Center
B. R. Fish
Health Physics Division

U. S. Public Health Service
Nat. Ctr. for Radiological Health
1901 Chapman Avenue
Rockville, Maryland 20852
Attn: Nuclear Facilities Section

D. B. Shuster, 1200
J. R. Holland, 5321
C. F. Bild, 7500
G. A. Fowler, 9000
J. R. Banister, 9150
R. C. Maydew, 9320
L. A. Hopkins, Jr., 9500
A. J. Clark, Jr., 9510
J. D. Shreve, 9511
S. L. Jeffers, 9512
ARPIC, 9512 (2)
S. McAlees, Jr., 9513
G. J. Hildebrandt, 9520
J. W. McKiernan, 9521
J. Jacobs, 9522
B. F. Hefley, 8232 (5)
B. R. Allen, 3422
C. H. Sproul, 3428-1 (5)
L. C. Baldwin, 3412
L. L. Alpaugh, 3412
G. C. McDonald, 3416 (2)
Attn: M. S. Goldstein, 3416