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SC-PR-69-434

July 1969

SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
APRIL 1 THROUGH JUNE 30, 1969

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AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

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SC-PR-69-434

SANDIA LABORATORIES QUARTERLY REPORT AEROSPACE NUCLEAR SAFETY PROGRAM APRIL 1 THROUGH JUNE 30, 1969

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

Sandia Laboratories, Albuquerque

Compiled by
R. G. Illing, 9514

July 1969

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ABSTRACT

This report describes research, development, support, and test activities in the Sandia Laboratories Aerospace Nuclear Safety Program from April 1 through June 30, 1969.

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SUMMARY

TRANSIT

A Safety Design Specification was prepared for the Transit heat source. Terminal velocities were calculated for an unablated hexagonal fuel block prepared by Isotopes for the Transit mission; terminal velocities and trajectories were calculated for four drop test configurations of Isotopes' fuel blocks and fuel capsules.

PIONEER RADIOISOTOPE THERMOELECTRIC GENERATOR

Droptests of four Pioneer heat source shapes were performed; the data are being reduced.

APOLLO LUNAR RADIOISOTOPIC HEATER (ALRH)

One temperature response of the ALRH after earth burial was determined.

ABORT MODEL

A trajectory was computed for the GLFC multiple-orbit problem; the TTA computer program indicated that the GLFC would reenter on the 22nd revolution.

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RADIOISOTOPE SYSTEMS SAFETY SUPPORT

SNAP-27

Radiant Heat Tests (L. L. Keller)

A report, SC-DR-69-60, SNAP-27 Fuel Capsule Assembly Radiant Heat Tests, was issued to document radiant heat tests performed by Sandia.

Fuel Leak Rate Tests (L. L. Keller)

A report, SC-DR-69-248, SNAP-27 Fuel Capsule Assembly Fuel Leak Rate Tests, was published to document fuel leak rate tests performed by Sandia.

Safety Studies (L. L. Keller)

A brief study was performed for AEC/SNS to evaluate the response of a fuel capsule assembly stored in a ground shipping cask to postulated environments created by a near-pad abort of a Minuteman at Cape Kennedy Air Force Station.

Helium Release from the SNAP-27 (S. M. Milly/C. J. M. Northrup, Jr.)

The launching of the fueled SNAP-27 generators is being delayed beyond the original scheduled date. Therefore, a modified version of HECON2, the computer program developed to predict the helium pressure in SNAP capsules, was used to examine four thermal histories of the fuel and to calculate the helium released from a SNAP-27. The results of the study indicate that from 54 to 92 percent of the helium generated since spheroidization could be freed in the capsule by the time of earth impact.

TRANSIT

Safety Design Specification (L. A. Hanchey)

A Safety Design Specification for the Transit heat source was prepared. It contains safety documentation requirements, safety design requirements, guidelines for safety evaluation models, and safety test requirements. The specification was forwarded to AEC Headquarters and to ALO with the intent that it be incorporated into the Transit contract.

Terminal Velocity of Isotopes' Proposed Fuel Block (H. R. Spahr)

Terminal velocities were calculated for an unablated hexagonal fuel block proposed by Isotopes for the Transit mission. The fuel block is 3.5 inches across flats, 6.75 inches long, and weighs 8.35 pounds. Terminal velocities were also calculated for a circular cylinder of the same weight inscribed inside the hexagonal fuel block. The circular cylinder provides a comparative configuration and would represent an upper bound on the terminal velocity of the ablated hexagonal configuration. The results were as follows:

<u>Orientation</u>	<u>Hexagonal Fuel Block Sea Level Terminal Velocity (fps)</u>	<u>Circular Cylinder Fuel Block Sea Level Terminal Velocity (fps)</u>
End-on	325	340
Crosswise	195 to 205*	355
Random tumbling	225	350

*Depends on roll orientation

The expected orientation of these configurations would be close to a random tumble.

Terminal Velocity and Trajectories of Four Drop Test Configurations (H. R. Spahr)

Terminal velocities were calculated for four Isotopes fuel block and fuel capsule configurations to be dropped by Sandia Laboratories at the Tonopah Test Range. The four configurations were:

1. Unablated hexagonal fuel block, 3.5 inches across flats, 6.75 inches long, and weighing 9.16 pounds.
2. Ablated hexagonal fuel block, as defined by Sandia Laboratories ablation studies, weighing 9.00 pounds.
3. Hemispherical-ended tapered cylinder fuel capsule, hemispherical end radius of 1.184 inches, tapered cylindrical section 3.530 inches long with a center radius of 2.470 inches.
4. Rectangular fuel block, 4.76 by 4.76 by 10.06 inches, weighing 8.598 pounds.

The results of these manual calculations, which ignore the atmospheric density gradient, are given in Table I.

Computer Code HRS016 was used with the Sandia Laboratories Quiktran remote terminal to compute trajectories for the four configurations in the expected random tumbling mode. These trajectories defined the impact velocities and range traveled for release at several altitudes above Tonopah for a horizontal velocity of 135.12 feet per second. The results are given in Table II.

These trajectories and the results in Table II show that:

1. A release altitude of 12,000 feet above the test range would permit all configurations, except the fuel capsule, to reach terminal velocity, and
2. A release altitude of 14,600 feet above the test range (the service ceiling of the available drop aircraft) would not permit the fuel capsule to reach terminal velocity if it falls as fast as predicted.

TABLE I

Terminal Velocities of Four Proposed Fuel Blocks

<u>Orientation</u>	<u>Drag Area (ft²)</u>	<u>Terminal Velocity at Sea Level (fps)</u>	<u>Terminal Velocity at Tonopah Test Range (fps)</u>
<u>Unablated Hexagonal Fuel Block</u>			
End-on	0.0663	341	370
Crosswise, edge-on	0.1673	215	233
Crosswise, flat surface- on	0.1875	203	220
Random tumbling	0.1404	234	254
<u>Ablated Hexagonal Fuel Block</u>			
End-on	0.0484	395	429
Crosswise, edge-on	0.1238	247	268
Crosswise, flat surface- on	0.1387	234	253
Random tumbling	0.1036	270	293
<u>Hemispherical Ended-Tapered Cylinder Fuel Capsule</u>			
End-on	0.010981	658	714
Crosswise	0.022470	460	499
Random tumbling	0.018640	505	548
<u>Rectangular Fuel Block</u>			
End-on	0.15734	214	232
Crosswise, edge-on	0.49881	120	131
Crosswise, flat surface- on	0.41568	132	143
Random tumbling	0.35728	142	154

TABLE II

Trajectories of Four Proposed Fuel Blocks

<u>Configuration</u>	<u>Release Altitude Above Tonopah Test Range (ft)</u>	<u>Tonopah Test Range Impact Velocity (fps)</u>	<u>Range Traveled (ft)</u>
Unablated hexagonal fuel block	14,600	258	1600
Unablated hexagonal fuel block	12,000	258	1510
Ablated hexagonal fuel block	14,600	299	1900
Ablated hexagonal fuel block	12,000	299	1800
Fuel Capsule	34,600	599	4600
Fuel Capsule	14,600	568	3200
Fuel Capsule	12,000	554	2900
Rectangular fuel block	14,600	155	770
Rectangular fuel block	12,000	155	710

Solid Rocket Propellant Fire Tests (F. L. Baker)

The first phase of the solid propellant burn tests is proceeding. The principle objectives of these preliminary 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.

Three tests were performed with solid propellant UTP 3001. The first test was instrumented with a disk-type flux gage and a cylindrical calorimeter. Photographic pyrometry was attempted but was not successful. The second test employed the cylindrical calorimeter, a ring-type slug calorimeter, a heat flux gage, and photographic pyrometry. Film from the photographic pyrometer was damaged in processing, and only limited data are available. A thermocouple on the heat flux gage failed early in the test, so no data are available from this flux measuring system. All data from the ring-type and cylindrical-type calorimeters appear good and are presently being analyzed. The third test was performed using the heat flux gage, small copper slugs for comparative temperature measurement, and the photographic pyrometer. The test appeared satisfactory, but no data are yet available. Documentary filming of test 1 was not successful, but it was good for test 2. The film from test 3 has not been processed.

PIONEER RADIOISOTOPE THERMOELECTRIC GENERATOR

SNAP-19 Intact Impact Capsule Terminal Velocity (H. R. Spahr)

The NASA Pioneer mission will be a fly-by of the planet Jupiter. Preliminary Earth terminal velocity calculations were completed for the SNAP-19 intact impact fuel capsule proposed for this mission. The results are as follows.

<u>Orientation</u>	<u>Terminal Velocity (fps)</u>
Side-on	189 to 327
End-on	325
Random tumble	214 to 327

Further terminal velocity calculations will be deferred until the ablated configuration after reentry is defined.

Drop Tests (R. E. Berry)

Four different shapes were fabricated and drop tested at the Tonopah Test Range. A total of 21 drops were completed on June 9 and 10; data were recovered from 19 of these tests. There were eight each of Shape No. 1, six each of Nos. 2 and 3, and one of Shape No. 4. A brief description of the shapes are as follows.

Shape No. 1 had a midpoint diameter of 2.47 inches. It tapered from this diameter to a hemispherical radius of 1.18 inches, and the body had a length of 5.9 inches. This shape simulated a heat source capsule without reentry protection. The weight of 5.7 pounds was based upon an 800-watt system.

Shape No. 2 was a hexagonal body 3.5 inches across flats and 6.75 inches long; it weighed 9.1 pounds. This body simulated the shape and weight of an 800-watt heat source capsule with reentry protection.

Shape No. 3 simulated Shape No. 2 after atmospheric reentry. Its shape also was hexagonal but with rounded corners. The shape was 3.45 inches across flats, 6.75 inches long, and weighed 8.8 pounds.

Shape No. 4 was a single drop unit provided by Isotopes and was a graphite body. It was 4.76 inches square, 10 inches long and weighed 8.6 pounds.

These drop items were manually released from an aircraft traveling at a forward velocity of approximately 165 ft/sec at a nominal altitude of about 16,000 feet mean sea level. Preliminary information indicates that at about 6200 feet mean sea level, or 800 feet above terrain, the velocities of the shapes averaged 453 ft/sec for Shape No. 1, 241 ft/sec for Shape No. 2, 326 ft/sec for Shape No. 3, and 128 ft/sec for Shape No. 4. Final data reduction will be completed shortly.

PIONEER/TRANSIT MULTIPURPOSE HEAT SOURCE (R. D. Klett)

A study was conducted to determine the feasibility of using a multipurpose heat source (MPHS) for both the SNAP-19/Pioneer and Isotec/Transit missions. The use of an MPHS in the Isotec would increase capsule operating temperatures, increase impact velocity, increase weight, and reduce versatility. A SNAP-19 with an MPHS would lose the multirevolution orbital decay capability that it has with the single purpose heat source.

Although the MPHS does not appear to be feasible, the same technology can be used in both heat sources. The use of capsules with the same construction and diameter but with different lengths is an attractive compromise between an MPHS and two different heat sources. Furthermore, if different insulators and ablative heat shields could be used for the two heat sources, the efficiency would be almost as high as two completely different heat sources with the only disadvantage being a slight weight penalty for the Isotec.

APOLLO LUNAR RADIOISOTOPIC HEATER (ALRH)

Thermal Analysis (D. W. Larson)

The temperature response of the ALRH after earth burial was determined. If the ALRH is buried such that the titanium clad is at 500°F initially, the titanium clad temperature after 100, 200, and 400 years would be 262°F, 156°F and 87°F, respectively. This thermal response was used to predict internal ALRH pressures with time, and subsequently, the stress in the titanium clad.

LARGE RADIOISOTOPIC HEAT SOURCE (LRHS) AND ISOTOPE REENTRY VEHICLE (IRV) (D. W. Larson)

The aerothermodynamic tests and analyses required to evaluate the safety and performance of the LRHS and the IRV were determined. The primary analyses required are: (1) a complete aerodynamic analysis, consisting of aerodynamic model determination and computing of trajectories for all the more probable abort conditions; (2) a complete ablation and thermal analysis based on launch pad and reentry abort environments; and (3) a thermal stress analysis if the design is such as to require it.

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY

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

BMI Cermet Specimen--A cylindrical $^{239}\text{PuO}_2$ molybdenum cermet specimen (P-32), which was fabricated by Battelle Memorial Institute, was tested on June 4, 1969. The cermet specimen, which was coated with approximately 0.002 inch of molybdenum and 0.004 inch of thoria, was 0.244 inch in diameter by 0.360 inch long. The purpose of the test was to allow comparison of this type of fuel specimen with other fuel candidates previously tested and to prepare for future tests of $^{238}\text{PuO}_2$ molybdenum cermet specimens.

The specimen was exposed for 30 seconds to test condition C in the Sandia 40 kW hyperthermal arc tunnel. Test condition C produces an enthalpy of 9500 Btu/lb, a model pressure of 0.0593 atmosphere, and a reference continuum heat flux of 87 Btu/ft^{3/2}-sec to the specimen. Figure 1 shows the specimen's front face and a portion of the cylindrical surface before and after testing. High speed movie films of the test indicated several "hot spots" on the front face of the specimen. These areas sheared away during the first second after exposure. Figure 2, which was taken from the movie films, shows this event. For the remainder of the test, only intermittent ablation of small pieces of the coating was evident. The posttest photos also reveal a longitudinal crack of the coating material on the cylindrical surface.

The specimen was sent to the Los Alamos Scientific Laboratory for posttest analysis. S. E. Bronisz of LASL sectioned the specimen's front face to determine the depth of the cracks and the degradation of the specimen's coating and inner fuel material resulting from the test. Figure 3 shows the sectioned front face in the area of the dark portion evident in Figure 1. There was obviously some reaction between the Mo, PuO_2 , and ThO_2 . LASL plans to conduct a microprobe analysis of the

BEFORE

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AFTER

BEFORE

AFTER

Figure 1. BMI test specimen P-32 before and after testing

Figure 2. Hot spots on specimen P-32

sectioned sample to better identify the materials in the damaged area and to determine the amount of reaction between materials. The longitudinal crack shown in Figure 1 also will be sectioned and analyzed.

Three more $^{239}\text{PuO}_2$ molybdenum and three $^{238}\text{PuO}_2$ molybdenum cermet specimens will be exposed to various other simulated reentry environments in order to determine the response of the fuel material to credible abort situations. A comprehensive report of all the tests, post-test analysis, conclusions, and recommendations will be published jointly by LASL and Sandia.

Rokide Specimens--Six ZrO_2 specimens fabricated from a commercial material called Rokide were tested in the 40 kW hyperthermal arc tunnel. The specimen dimensions were 0.250 inch in diameter by 0.372 inch long. These specimens were subjected to various environments which simulated the integrated heat flux of reentry abort situations of the Transit system. The purpose of the test series was to observe the response of ZrO_2 to actual integrated reentry heat fluxes and times in lieu of the standard test conditions and times normally used to compare fuel candidates.

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Figure 3. BMI test specimen P-32 before and after testing

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Table III presents the test parameters and mass lost from the specimens during the tests. In test runs Nos. 586, 587, 589, and 590, the mass lost was small and is believed to be partly due to vaporization of machining oil from the specimens. The mass lost from specimen RZ-3 during run No. 588 was more significant and resulted from a credible abort simulation. It should be noted that test runs Nos. 590 and 591 simulated a fuel puck edge-on reentry. This mode of reentry is highly improbable. These two tests were conducted merely to gain data on the response of ZrO_2 at higher integrated heat fluxes and should not be construed as valid reentry situations.

Increased Efficiency of HECON2 Helium Release Calculations (S. M. Milly/C. J. M. Northrup, Jr.)

HECON2, the computer program developed to predict helium release from alpha-emitting fuels, was modified recently to minimize the time required to analyze a fuel capsule's behavior. Multiple node analyses can be handled on either the CDC 3600 or 6600 computers, with complicated histories typically being completed in minutes. Subroutines were added to reduce the time needed to prepare the input and to calculate time increments which will keep the truncation error minimal while reducing the operational computing time. The program handles special situations such as storage, incapsulation, launch pad aborts, and reentries. A number of print options are available to examine either vented or unvented systems in as much detail as required. Another subroutine option is being written to automatically plot the system's behavior (helium release versus time, capsule pressure versus time).

FLIGHT TEST STUDY

Reentry Simulation Tests (A. C. Bustamente)

A study to investigate the feasibility of reentry simulation through flight testing is almost complete. Various aerothermodynamic parameters which describe suborbital, orbital, and superorbital reentry environments are being defined. A comparison of aerothermo parameters for some abort conditions of a Transit-type capsule and for an Athena H flight test was made and appears good (Figure 4).

TABLE III
ZrO₂ Test Specimens - Transit Reentry

<u>Test Run Number</u>	<u>Specimen Number</u>	<u>Test Condition</u>	<u>Reference Continuum Heat Flux (Btu/ft^{3/2}-sec)</u>	<u>Time of Exposure (sec)</u>	<u>Mass Loss (%)</u>	<u>Transit Abort Situation</u>
586	RZ-2	S	72	6	0.167	Fourth stage failure; face-on puck out at $\frac{1}{2}$ peak heat.
587	RZ-1	B	108	2	0.125	Fourth stage failure; face-on puck out at peak heat.
588	RZ-3	K	160	4	2.140	Scout low dispersion trajectory; face-on puck.
589	RZ-4	S	72	80	0.312	Orbital decay; face-on puck.
590	RZ-5	B	108	320	0.204	Orbital decay; edge-on puck.
591	RZ-6	K	160	215	~ 10	Orbital decay, edge-on puck.

Integrated Heat Rate, $\int_0^t \dot{q} dt$, for 1' Radius Sphere (Btu/ft² x 10⁻³)

Figure 4. Comparison of aerothermo parameters for a Transit Abort and an Athena "H" flight condition

ABORT MODEL

Multiple-Orbit Reentry (D. W. Larson/H. R. Spahr)

A trajectory was computed for the GLFC multiple-orbit problem; the initial perigee altitude was 300,000 feet. By using the TTA trajectory program logic to compute only the atmospheric portion of the GLFC trajectory, the computer time required was reduced from an estimated 15 hours to 0.5 hour. The GLFC reentered on the 22nd revolution.

Computations for the same conditions using the HRS017 approximate closed form solution code had predicted reentry on the 65th revolution. While the TTA predicts less orbits, the aerodynamic heating rates are higher on the later orbits. These effects were expected and compensate for ablation calculations. Results of ablation calculations using the two calculated reentry environments show that the TTA reentry environment predicted 40 percent less ablation than the HRS017 results.

A similar comparison of results for the ALRH 280,000 perigee point showed that the TTA results predict 30 percent less ablation than the HRS017 results. At a lower perigee altitude of 260,000 feet for the ALRH, the TTA results predicted 13 percent less ablation than the HRS017 results.

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

A one-dimensional cylindrical thermal model was constructed for use with the CINDA computer code to check out the thermal analysis portion of a combined thermal analysis and thermal stress analysis computer code being developed by Sandia. The combined code operated satisfactorily for all the different boundary conditions that were checked.

Computer Code HRS004 (H. R. Spahr)

Three versions of this code calculate initial trajectory conditions for objects decaying from Earth orbits. Information on this code was submitted for inclusion in the next supplement to the Sandia Laboratories Aerothermodynamic Program Library report.

Computer Code HRS015 (H. R. Spahr)

This code, which calculates the transition flow hypersonic ballistic coefficient of blunt objects, is now operational on the Sandia Laboratories CDC 3600 and Univac 1108. At the request of AEC/ALO, this code was submitted to Computer Software Management and Information Center (COSMIC). Information on this code was submitted for inclusion in the next supplement to the Sandia Laboratories Aerothermodynamic Program Library report.

Project PYRO (R. E. Berry)

A limited number of Project PYRO magnetic data tapes were borrowed from the Air Force Rocket Propulsion Laboratory for the purpose of establishing near-field pressure environment by analytical techniques. The intent is to prepare a computer code which will convert pressure-time histories to energy-frequency information and then extrapolate this energy-frequency information to a greater or lesser distance by evaluating energy loss as a function of attenuation and distance. The new energy-frequency data are then analyzed to obtain a new pressure-time history at the new distance. After the computer code has been shown to accurately extrapolate from one PYRO data station to another PYRO data station, the code will be used to extrapolate toward the missile to provide a near-field pressure environment.

DEMOGRAPHIC MODELS

Soil Distribution Model (L. L. Keller)

A report is being prepared to document a study performed by Atomics International under contract to Sandia. Sources of data, compilation methods, and utilization of the data for the worldwide soil distribution model are discussed. The soil distribution model is available on 9-track magnetic tape for the IBM 360 Model 50 computer.

ENVIRONMENTAL TRANSPORT MODELS (H. W. Church/R. E. Luna/
S. M. Milly/B. H. Simon)

The two computer codes for calculating (1) the fall and dispersion of particles in the atmosphere (Model B) and (2) aerosol transport and diffusion in the atmosphere (DIFOUT) were successfully converted to operate on the Sandia CDC 6600.

Two subroutines were written which, together, use a four point cell method to contour a function of two variables and to compute the areas enclosed by the contours. These routines, designated PLOTR and XYGRD, were written in Fortran V for the CDC 6600 and utilize the SCORS plotting routines to produce a output tape for the SC-4020 micro-film plotter. This system may be used by any calling program to contour the function $F(x,y)$ where F is tabulated in a two-dimensional array with indexes x,y corresponding to either cartesian or polar coordinates. The system was successfully operated in program DIFOUT to contour and calculate areas of ground level air dosage or deposit values. A report on the routines is in preparation.

Program STREAK, a successor to STARDUST, developed at Isotopes (Westwood, N. J.), is currently undergoing extensive revision and modification at Sandia. The program was designed to calculate two-dimensional diffusion of injected radioactive tracers in a meridional plane of the atmosphere. This plane extended from the north to the south pole and from ground level to 40 km altitude. The diffusion is anisotropic with the principal axis parallel to the tropopause. Non-diffusive effects included are atmospheric removal processes by rainout and dry deposit at the earth's surface. The selection of these calculational features and required specific constants were tested against data and carefully selected by Isotopes for optimum reproduction of observations.

Principal modifications completed to date are: (1) increase of upper boundary from 40 to 90 km; (2) installation of generalized input logic for particle size, source configuration, and time of injection in order to avoid rewriting the code for each job, as was required previously; (3) subdivision of the program in order to aid in understanding of computational procedure; and (4) generalization of portions of the code which were used only for a specialized problem.

Complete mathematical and logic analyses of the code were required since detailed documentation was lacking. These analyses, detailed descriptions of usage, and compatibility of the model are currently being prepared for a report.

Assembly of the wind tunnel in the particulate transport laboratory is about 98 percent complete. This tunnel is to be used for the study of small particle behavior near arbitrary boundaries in controlled turbulence. As soon as installation of required flow measuring and characterization devices is made, calibration runs can proceed.

SPECIAL STUDIES

Burial Temperatures (G. H. Elkins)

Soil temperatures resulting from buried radioisotopic fuel capsules were calculated as a function of distance from the heaters for two different geometries and ten different soils. The geometries considered were for cylindrical and spherical heaters. The following soils were used:

- Calcareous
- Granitic detrital
- Dune sand
- Magnesian
- Podzol
- Coastal plains
- Laterite
- Estancia playa
- Two samples of Ottawa sand

The temperature dependent thermal conductivities presented in SC-CR-69-3059, Measurements of the Thermal Conductivity of Soils to High Temperatures, were used in the calculations. The results of this investigation will be reported in a topical report when all calculations are completed.

Hexagonal Prism Ablation (R. D. Klett/D. W. Larson)

An ablation analysis of a hexagonal prism with a spinning cross-flow orientation showed that the edges would be rounded significantly early in an orbital decay heat pulse and before peak heating during a -6.25 degree lunar return reentry. The edges would be rounded enough to reduce the average heating at the edges by 36 percent 180 seconds before peak heating during an orbital decay reentry. At this time, the average heating to the hexagon is only 5 percent higher than that of a spinning cylinder in crossflow. Rounding of the edges continues until earth impact but at a decreasing rate as the heating distribution becomes more uniform. Impact velocities of an ablated hexagon should be closer to the impact velocity of a cylinder than those of a sharp cornered hexagon.

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