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**AEROSPACE
NUCLEAR
SAFETY**

SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER 1 THROUGH DECEMBER 31, 1970

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BY JH Kahn / amb
DATE 3/16/71

AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

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N O T I C E

At the end of calendar year 1970 all work at Sandia Laboratories relative to Space Isotope Power Systems and Aerospace Nuclear Safety was terminated, except for several small efforts in support of existing projects. These efforts will be terminated as soon as they can be stopped effectively and efficiently; this will be in the near future.

Therefore, this issue of the Aerospace Nuclear Safety Quarterly Report on our ANS activities will be the last report issued.

A complete bibliography of all reports on Space Isotope Power and Aerospace Nuclear Safety issued by Sandia from 1962 through 1970 is contained in report SC-ARPIC-1014, dated December 1970. The bibliography is available from AEC/DTIE and NTIC.

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SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER 1 THROUGH DECEMBER 31, 1970

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December 1970

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ABSTRACT

This report describes research, development, support, and test activities in Sandia Laboratories Aerospace Nuclear Safety Program from October 1 through December 31, 1970.

The cutoff date for information in
this report is December 30, 1970.

Key words: Pioneer, DART, HAVE SINEW

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SUMMARY

PIONEER

Five Sandia trajectories were selected for thermal stress analysis of the Pioneer heat shield; thermal stress calculations were carried out for two of the trajectories, and the results indicated no thermal stress failure of the heat shield; however, the remaining three trajectories will generate much more severe thermal stresses. The low and high yield overpressure tests of complete Pioneer RTGs were conducted; in both tests, the generator housing and the graphite heat shield were shattered and the bare capsule was found intact. The low velocity fragment test of a Pioneer capsule was conducted; the capsule was recovered intact, but the clad was breached and the strength member was exposed. Two liquid fire tests were performed using Pioneer capsules; neither capsule was significantly damaged.

HAVE SINEW-1

This program was formerly known as FLINTNOSE, and the flight test is now scheduled for May 1971. The final Safety Analysis Summary is being prepared. The handling, installation, and health physics procedures for ^{182}Ta are complete. The flight trajectory for HAVE SINEW-1 was fixed by Atlantic Research, and the flight environment analysis has been started for each of the five different heat sources.

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RADIOISOTOPE SYSTEMS SAFETY SUPPORT

TRANSIT

Reentry Verification Tests (D. E. Randall)

Four Transit heat sources in the Inconel cans were subjected to a simulated orbital decay heat pulse in the NASA/MSC 10 MW arc-jet facility. These tests were part of a sequential test series to which these heat sources were subjected. A fifth heat source was exposed to a thermal shock pulse consisting of insertion cold into the peak facility thermal environment of $q\sqrt{R} \approx 105 \text{ Btu/ft}^{3/2} \text{ sec.}$

PIONEER

Reentry Verification Test Plan (D. E. Randall)

Seven Pioneer heat sources were scheduled for reentry thermal testing at the NASA/MSC 10 MW arc-jet facility. This test series is a part of a sequential test series to which these heat sources are to be subjected. The arc-jet test program was reviewed in conjunction with a review of the sequential test series at AEC Headquarters September 24, 1970.

Thermal Stresses (R. E. D. Stewart)

Five Sandia trajectories were selected for thermal stress analysis of the Pioneer heat shield. These trajectories represent a cross section of the severity of the various reentry environments to which the Pioneer could conceivably be subjected. Initial conditions for the five trajectories selected are:

<u>Trajectory Description</u>	<u>Altitude (ft)</u>	<u>Angle (deg)</u>	<u>Velocity (ft/sec)</u>
Orbital decay	450,000	- 0.01074	25,678
Shallow superorbital	400,000	- 6.0	36,000
Steep superorbital	400,000	-28.0	36,000
Fast multiorbit	400,000	- 6.3	43,700
Hover	400,000	- 8.9	44,000

The thermal stress calculations are being carried out using a modified version of computer code SAAS II. Input to the thermal stress code is furnished as output by Sandia's thermal code CINDA in the form of a magnetic tape which lists the temperature distribution in the heat shield as a function of time throughout the trajectory. Output from the thermal stress code consists of the corresponding stress and strain distributions in the heat shield as a function of time throughout the trajectory. The thermal stress code contains a mesh generation subroutine which can be used to generate a finite element meshwork compatible with the hexagonal geometry of the heat shield. Figure 1 is a transverse cross section of the Pioneer heat shield showing the computer generated finite element meshwork of the thermal stress model. The thermal stress code also accurately accounts for the temperature dependency of material properties. The only limitations of the computer analysis are: (1) a state of plane strain is assumed, and (2) the deformation behavior of the material is approximated using a bilinearly elastic material modulus. These limitations are not expected to introduce any serious errors in the thermal stresses.

Figure 1. Pioneer heat shield transverse model

To date, thermal stress calculations have been carried out for the first two of the five trajectories listed above. Neither of these calculations indicated thermal stress failure of the heat shield.

However, much higher thermal stresses can be expected for the remaining three trajectories.

In addition to the five Sandia trajectories selected for thermal stress analysis, Sandia has agreed to perform additional thermal stress calculations, as time permits, based on trajectory and thermal data generated by Isotopes, provided Isotopes can furnish these data in a form directly usable as input to Sandia's thermal stress code. Detailed information regarding the required form of these input data was transmitted to Isotopes, but no reply has been received as yet. In the meantime, Isotopes indicated that they are continuing their efforts to evaluate Pioneer thermal stresses using an idealized analytical model. The major limitations of the idealized analytical model are

1. Inability to handle the hexagonal geometry of the heat shield (the analytical model idealizes the geometry to a hollow circular cylinder);
2. Inability to satisfactorily account for the temperature and strain dependence of material properties; and
3. Inability to describe accurately the actual temperature distribution in the heat shield (the analytical model assumes that the temperature distribution satisfies the steady-state Laplace equation).

Overpressure Tests (F. L. Baker)

The low yield overpressure test was conducted in the 6-foot shock tube at the Sandia Coyote test area. The test unit was a complete generator, Unit Pl2, which was preheated to 350°F. Test parameters achieved were a static overpressure of 301 psig and a static impulse of 1.7 psi-sec. The generator housing and the graphite heat shield were shattered; the bare capsule was found intact, with no visible damage, approximately 250 feet down range from the shock tube muzzle. The health physics radiation monitoring on the capsule was negative.

The high yield open field overpressure test was conducted at the Sandia Coyote test area. The test unit was a complete generator, Unit Pl3, which was preheated to a temperature of 350°F. A hemispherical TNT charge weighing 466 pounds was detonated at ground level. The Pioneer RTG was mounted on a simulated mounting fixture and was located

to provide a 57-inch spacing from the center of the charge to the center of the RTG. Preliminary indications are that the test parameters achieved were a peak static overpressure of 1800 psig and a shock velocity of Mach 10.7. The generator housing and the graphite heat shield were shattered. The bare capsule was recovered intact. It had experienced some deformation on the side directly exposed to the blast, but there were no visible breaches in the clad material.

Fragment Test (F. L. Baker)

The low velocity "black box" fragment test was performed using the Sandia sled track. The telemetry package weighed 38.5 pounds and was carried on a lightweight outrigger which was bolted to the utility sled. The box was positioned so that the center of impact was edge-to-edge through the long dimension, with the connectors facing forward. The test unit was capsule P12; this was the capsule recovered from the low yield overpressure test. The capsule was heated to a temperature of 1850°F in an argon gas atmosphere. The desired velocity was 410 fps, and the measured velocity was 409 fps. The capsule was recovered intact following the test, but the clad was breached and the strength member was exposed.

Liquid Fire Tests (F. L. Baker)

Two liquid (JP-4) fire tests were performed in Sandia's Lurance Canyon test area. The capsules were preheated to a temperature of 1850°F in an argon atmosphere. They were suspended in a stainless-steel basket 24 inches above the fuel level. The basket was lined with platinum foil strips to prevent materials interaction between the capsule and basket.

The first test was conducted with capsule P19. The propellant burn time was 33 minutes and 35 seconds. Wind conditions during the test were calm to 5 mph. A posttest visual examination revealed no damage to the capsule. The health physics radiation monitoring was negative.

The second test was conducted with capsule P12 which had previously experienced the shock tube overpressure and the black box fragment tests. The test configuration was a bare capsule with the clad

breached as a result of the fragment test. The burn time for the test was approximately 34.5 minutes. Wind velocity during the test was less than 10 mph. A posttest visual examination revealed that the strength member had experienced some oxidation in the areas that had been exposed in the fragment test. The health physics radiation monitoring was negative.

Solid Propellant Direct Contact Fire Test (F. L. Baker)

The solid propellant burn tests are being performed with the TE 364-4 rocket motor propellant, TP-H-3062. The sample blocks of propellant are each 12 inches wide, 12 inches thick and 18 inches long; they weigh approximately 70 pounds each. The capsules are heated to a temperature of 1850°F in an argon gas atmosphere.

The first direct contact solid propellant fire test was attempted with test capsule P19 at Sandia's Lurance Canyon test area. The transport mechanism, which was to move the capsule from the oven to the propellant block, malfunctioned, and the capsule was positioned at the edge of the block. When the platinum wire cradle burned through, the capsule fell off the block and received a very limited exposure to the planned environment. Damage experienced by the capsule was limited to a small area of melted clad on one hemispherical end; the damage was documented on film. The capsule was considered salvageable for a retest. The propellant burn time was 4.5 minutes.

The second direct contact test was performed in the same area. Two capsules, P12 and P19, were used for this test. P19 had previously experienced the liquid fire and the unsuccessful solid contact fire tests. P12 had previously been exposed to the low overpressure, black box fragment, and the liquid fire tests. The propellant burned for 4 minutes and 45 seconds. The copper calorimeter used in this test almost completely melted. It formed a pool of copper that, on cooling, formed a solid mass with the capsules frozen in the copper. A posttest visual examination of the capsules revealed a heavy coating of the fire residue, i.e., aluminum and aluminum oxide.

Because of the heavy residue coating, the condition of the capsules could not be readily determined. Initial health physics radiation monitoring of the capsules was negative. A closer visual

inspection of the capsules in the Health Physics laboratory revealed that a small area on the end of each capsule had either melted or corroded through the capsule, exposing the fuel discs. Both capsules were sent to LASL for postmortem examination.

MULTI-HUNDRED WATT LONG-LIFE RTG SYSTEM

Phase I Final Report (D. E. Randall)

The estimated reentry performance of this system was reviewed. The commentary was reviewed and discussed with General Electric representatives.

DART MINITHRUSTER

Simulated Launch Abort Tests (F. L. Baker)

The final test in the series of simulated launch abort tests of the DART Minithruster capsule was completed. The final test in this series was the direct contact, solid propellant fire test which was performed with the Pioneer direct contact test. The sample propellant was a block of TP-H-3062 12 inches wide, 12 inches thick, and 18 inches in length; it was inhibited on all surfaces except the top. DART test unit 1 had been previously subjected to a 600 psi overpressure test. In the overpressure test, the graphite heat shield was shattered; this resulted in a bare TZM capsule for this test. The propellant burned for 4 minutes and 45 seconds. Posttest visual inspection revealed that the capsule had melted, and it appeared that the fuel can had been breached. Health physics radiation monitoring indicated an activity level of 200 mCi/min. The unit is to be x-rayed and then returned to LASL for postmortem. The other tests in this series were reported in SC-PR-70-435.*

*SC-PR-70-435, Sandia Laboratories Quarterly Report Aerospace Nuclear Safety Program April 1 Through June 30, 1970, Aerospace Nuclear Safety Department 9510, Sandia Laboratories, Albuquerque, New Mexico, July 1970.

SAFETY TECHNOLOGY

ADVANCED FUEL SAFETY

Isotope Fuels Impact Facility (IFIF) (W. J. Dalby)

Installation of the vertical air gun and auxiliary equipment (i.e., lights, control and monitoring circuitry, ventilation system, working platform, hoist, etc.) in and adjacent to the steel containment vessel was completed. A trial test was completed, and the approvals of Sandia's Test Operations Hazards Committee and Sandia's Environmental Health Operations Division were obtained to proceed with the impact testing of ^{238}Pu at temperatures and velocities up to 850°F and 320 fps. The initial intent was to provide a facility to accommodate impact tests of sources up to approximately 2400 curies. Preliminary approval was limited to approximately 1200-curie sources because this appeared to be adequate for immediate needs.

Fuel Impact (W. J. Dalby)

Five impact tests of individual disks were completed, and the capsules were returned to LASL for particle size distribution analyses. The test specimens and conditions are described in Table I.

TABLE I
Test Specimens and Test Conditions

Test Date	Specimen Identification	Capsule Number	Impact Velocity (ft/sec)	Temperature (°F)	Impact Attitude* (deg)	Disk Size (approximate) (in.)	Disk Material
11/ 5/70	D0211-24	A-4	432	840 to 860	45	2.12 dia x 0.21 thick	SSCS
11/19/70	D1017-9-3	D-2	315	840 to 860	0	0.5 dia x 0.21 thick	SSCS
11/21/70	Sample A	D-4	314	840 to 860	0	0.5 dia x 0.21 thick	PMC
11/24/70	Sample B	D-5	306	840 to 860	0	0.5 dia x 0.21 thick	PMC
11/25/70	D1017-9-4	D-3	311	840 to 860	0	0.5 dia x 0.21 thick	SSCS
*0-degree cylindrical axis of disk parallel to velocity vector and perpendicular to target face.							

Alpha Irradiation of Molybdenum Foils (C. J. M. Northrup, Jr./
R. P. Wemple/G. J. Thomas/C. R. Hills)

Molybdenum foils irradiated at LRL, stored at room temperature for 1 year, and then annealed to temperatures as high as 1600°C were examined with the metallograph. The alpha doses simulated 0.39, 0.5, and 2.2 year exposures to $^{238}\text{PuO}_2$. After annealing, unirradiated areas of the foils show the expected large grains indicative of normal grain growth above the recrystallization temperature. This growth is usually initiated near 800°C in unirradiated molybdenum. The behavior of the irradiated metal, on the other hand, was in marked contrast to the unirradiated material. Most of the grains of the irradiated molybdenum remained small even after the metal had been annealed for hours at hundreds of degrees centigrade above the recrystallization temperature. No visual difference in the gross metal structure was visible at temperatures of 700°C and below. However, earlier studies indicate significant embrittlement at lower temperatures can be induced by alpha damage. Only at high temperatures were changes visually observed in the gross structure of the metal.

Analysis by mass spectroscopy indicates that in low dose samples much of the helium is retained until high temperatures are reached. This behavior is consistent with transmission electron microscopy that shows bubble formation and migration of the bubbles to grain boundaries near 1000°C. Bubbles located on the grain boundaries impede subsequent grain growth. It remains to be seen if the fracture behavior of molybdenum is changed by the presence of bubbles at the grain boundaries, but this seems most probable.

The gas release behavior of the molybdenum was found to be a strong function of the total alpha dose. As the dose increased, the release of the first 40 percent of the helium did not occur until higher temperatures were reached. In 2.2-year simulated specimens, this trend changed, with large bursts of gas occurring on heat up to 200°C. The behavior is consistent with the model of increased helium retention in bubbles with increasing dose until a high dose is attained. After receiving a high dose, the grain structure may be disrupted sufficiently to permit an easy passage of gas even at lower temperatures.

HAVE SINEW-1

Program Name and Flight Date Change (A. C. Bustamante)

The FLINTNOSE flight test program name was changed to HAVE SINEW. This new program name is not an acronym but an Air Force designated code name. In addition, the flight date was changed from February 1971 to May 1971.

Detailed Flight Test Plan (DFTP) (A. C. Bustamante/ J. E. Deveney)

A Detailed Flight Test Plan report (SC-RR-70-855) was prepared and distributed to all cognizant agencies involved in the HAVE SINEW-1 test. This document provides the basis for all experiment planning information required of support agencies for the HAVE SINEW-1 test. In addition, the DFTP contains the complete and comprehensive treatment of the experiment details, total support requirements, and test objectives.

Interface Control Drawings (ICD) (A. C. Bustamante)

The electrical and mechanical inputs for the ICD were completed and furnished to Atlantic Research Corporation. Formal approval of the ICD is expected at the ICD review meeting in January 1971.

Alternate Payload Support Adapter (APSA) (A. C. Bustamante/ J. E. Deveney)

Various memorandums were formally transmitted to SAMSO, Aerospace, Corporation, and Atlantic Research; the memorandums outline and define Sandia's design requirements and limitations with regard to the APSA design. The various items covered were the mounting of the payloads, retaining strap, allowable stresses and loads on the payloads, electrical requirements, handling equipment, and payload interchangeability.

Plans were made to conduct a spin test of the APSA in the Sandia vacuum sphere facility. The purpose of the test is to evaluate the release characteristics of the various payload units. This test is scheduled for early February 1971.

Safety Analysis Summary (SAS) (A. C. Bustamante)

The final SAS is being prepared. The handling and installation procedures for tantalum 182 are complete. The health physics procedures also are complete. These procedures were presented at the launch complex orientation meeting at Green River, Utah, on November 13, 1970. Sandia representatives will be responsible for the installation of ^{182}Ta in the heat sources and Sandia will be the radiological health physics monitoring agency.

Special handling equipment was designed for the installation of radioactive tracers on the heat sources and for the placement of the heat sources on the APSA.

Radar Cross Sections (A. C. Bustamante/J. E. Deveney)

The graphite ablator shells of Sandia payload units 1, 2, 3, and 4 are being measured for radar cross sections. These patterns will be used to aid radar tracking of the flight payloads and, if possible, to distinguish between units during flight.

Payload Configuration/Objective Agreement (PC/OA)
(A. C. Bustamante/J. E. Deveney)

The PC/OA was formally approved in the Athena H/secondary payload integration meeting, held at Costa Mesa, California, on September 23 and 24. This document reflects certain requirements to be adhered to by Atlantic Research and Sandia Laboratories in support of the second Athena H research and development test. Sandia, SAMSO, Aerospace Corporation, and Atlantic Research Corporation signed the document.

Program Requirements Document (PRD) (A. C. Bustamante)

Input into the Program Requirements Document (PRD) was prepared, and submitted to White Sands Missile Range. The PRD provides the White Sands Missile Range with a complete description of the support requirements for HAVE SINEW-1 payloads.

Flight Environment Analysis (A. C. Bustamante)

The initial reentry conditions for the HAVE SINEW-1 flight are defined and fixed by Atlantic Research as follows:

1. Minimum altitude at payload release (ft): 275K
(299K nominal)
2. Flight path angle at PSA (deg): -20 ± 1
3. Velocity at PSA (fps): $21,650 \pm 300$

Since the flight trajectory is now fixed, the flight environment analysis has been started for each of the five different heat sources. The areas that will be covered in this analysis include the following for each heat source:

1. Trajectory Analyses
 - a. Dispersion and impact.
 - b. Complete trajectory.
 - c. Heating rate and integrated heat.
2. Aerothermo Analyses
 - a. Heating distribution.
 - b. Temperature distribution both externally and internally.
 - c. Thermal shock (1st order); a second order analysis will be done if such is indicated by the preliminary analysis.
 - d. Ablation analysis.
 - e. Temperature history on the heat source throughout the complete trajectory until impact.
 - f. ^{182}Ta temperature analysis.
3. Aerodynamic and Dynamic Analyses
 - a. Complete variation of $W/C_D A$ with Mach number and altitude.
 - b. Motion analysis during reentry and during separation from the APSA.
 - c. Aerodynamic loading and vibration.

4. Radiation Analysis

- a. Effect of gamma photons on instrumented package.

5. Mechanical Analyses

- a. Complete mechanical and dynamical review of design of the payload adapter (APSA).
- b. Vibration and load analysis.

6. Environmental Tests

- a. Spin test of APSA and payloads to test APSA design and payload ejection.
- b. Drop tests of instrumented heat source.
- c. Vibration and shake table tests.
- d. Radiation test (gamma) on instrumentation package.
- e. RF and heat test on the instrumentation.

The above is intended as a general outline; some of the above items were completed.

Status of Instrumented Unit No. 1 (A. C. Bustamante/
J. E. Deveney)

Three billets of ATJ graphite were received and machined as ablator shells for the ENVIRONMENTAL test program on the flight instrumented unit. Four billets of POCO graphite AXF-5Q were shipped in December for the flight test hardware. Two sets of fibrous carbon insulators were received. The final two sets will be fabricated in December. This special insulator was developed by the Materials Department of Sandia Laboratories.

Fabrication and assembly of an instrumented unit (without heat shield, insulator, or thermocouples) is complete. The sequential assembly of the instrumented package is shown in Figures 2 through 13.

Figure 2. Data recording assembly for
HAVE SINEW-1 reentry package

Figure 3. Component housing structure

Figure 4. VCO, batteries, rate gyro, and commutator for HAVE SINEW-1 package

Figure 5. Printed circuit boards

Figure 6. Tape Recorder

Figure 7. HAVE SINEW-1 reentry package
before assembly

Figure 8. HAVE SINEW-1 reentry package
before assembly

Figure 9. Partially assembled package

Figure 10. Partially assembled package

Figure 11. Assembled package

Figure 12. Wired, assembled package

Figure 13. Wired, assembled package

Tonopah Drop Tests (A. C. Bustamante/J. E. Deveney)

Two drop test models of instrumented unit No. 1 were dropped from a C-47 aircraft at Tonopah Test Range on December 15, 1970. Unit A was a ballistic unit and consisted of:

1. ATJ graphite ablator shell,
2. dummy insulator of balsa wood, and
3. weighted mass simulating instruments.

Unit B was an instrument unit and consisted of:

1. ATJ graphite ablator shell,
2. fibrous carbon insulator,
3. a tape recorder with prerecorded tapes, and
4. dummy instruments.

Radar coverage was obtained on both units.

The terminal velocity at impact was 320 fps. Camera coverage was obtained on unit B.

Both units were recovered, and the instrumentation can and shell on unit B incurred no damage. Playback of the recovered tape showed no damage to the prerecorded tape, and the playback data were good.

TRW Briefing (A. C. Bustamante)

A meeting was held at TRW, Redondo Beach, California, to discuss the various aspects of the HAVE SINEW-1 flight test pertinent to the Transit heat source.

Infrared Tracking (A. C. Bustamante)

Discussions were held with an Aerospace Corporation representative concerning an infrared tracking system that might be used for tracking HAVE SINEW-1 payloads. Preliminary calculations indicate that this system could be capable of tracking the payloads.

Flight Test Program (D. E. Randall)

Fifteen reentry trajectories were computed for the five payload configurations in end-on, side-on, and end-over-end tumble orientations. In the absence of the booster launch trajectory, the nominal separation condition was used for these reentry trajectories which provide a definition of the reentry environment for the various payloads.

SPECIAL ANALYSIS

Tulip Problem (A. C. Bustamante/J. E. Deveney)

A telephone call, followed by a telex, was received from Mr. Schniewind of the European Space Technology Center (ESRO), Noordwijk, Netherlands, requesting an opinion and consultation on a reentry problem that they were having with a rocket-launched reentry payload.

An approximate analysis was conducted to solve ESRO's immediate problem, and recommendations were made and forwarded via telex which gave a solution for their payload which was scheduled for launching in December 1970 from Sardinia.

The payload was launched on December 6, 1970, and all phases of the flight were successful, in particular the reentry phase. Personal thanks were received via telex from Mr. Eaton (head of Sounding Rockets, ESTEC) and Mr. J. Schniewind.

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