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PIONEER RTG SAFETY EVALUATION:
PHASE I IMPACT AND LAUNCH ABORT
SEQUENTIAL TESTS

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PIONEER RTG SAFETY EVALUATION:
PHASE I IMPACT AND LAUNCH ABORT SEQUENTIAL TESTS

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May 1971

ABSTRACT

Phase I impact and the launch abort sequential tests were performed by the Directorate of Environmental Sciences under the technical direction of the Aerospace Nuclear Safety Department to investigate the Pioneer RTG heat source response to postreentry impacts and Atlas/Centaur/TE-364 launch abort environments. A description of each test and the results are presented. The test levels used in this test program were based on reference environments defined as the maximum levels expected from the various aborts. Thus, these levels are considered conservative. The response of the capsules to the environments imposed was generally good. However, two capsules in the impact tests and two capsules in the solid propellant direct contact fire test were breached.

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SUMMARY

A safety test program was conducted by the Directorate of Environmental Sciences under the technical direction of the Aerospace Nuclear Safety Department in support of the AEC's Pioneer RTG program. Two test series were conducted. The first series consisted of three impact tests designed to assess the correlation between the impact responses of the Pioneer and Transit capsules to similar impact conditions and to evaluate the radioactive fuel containment integrity of the Pioneer capsule. The second series was a launch abort sequence designed to expose the Pioneer capsule to the cumulative effects of the environments, i. e., overpressure, fragments, and propellant fires predicted in a launch pad abort of the Atlas/Centaur/TE-364. All the test items were x-rayed before testing to insure proper assembly and readiness for testing. The radiographs indicated all units were acceptable for test.

The impact tests were conducted on Pioneer heat sources P-8, P-10 and P-11. The test items consisted of the capsule and heat shield except that Poco AXM-5Q graphite was used in lieu of the Poco AXF-Q1 graphite specified in the actual flight hardware. The pyrolytic graphite sleeves were omitted from the assembly and the Poco AXM-5Q was machined with extra thickness in that area to properly hold the capsule.

The test conditions specified for the impact tests were a velocity of 326 fps, 2400°F strength member temperature, and orientation of the cylindrical axis of the capsules at angles of 0°, 22.5°, and 45° to the velocity vector of the target block. The test items were impacted by a two foot cube of Escondido granite. Unit P-10 was intact following the impact; Unit P-8 experienced cracking of the clad, strength member, and liner, and unit P-11 had a crack that extended through the clad, strength member, and liner.

The sequential test series was conducted on six units. Three configurations were tested, i. e., Pioneer generator assembly, heat source, and bare capsule. In sequential testing, the test item at each succeeding level consisted of the capsule or heat source in the as tested condition from the preceeding test.

The first tests of the sequential series were two overpressure tests conducted on Pioneer generator assemblies P-12 and P-13. Unit P-12 was subjected to a static overpressure of 305 psig and a static impulse of 1.7 psi-sec in a shock tube test; the generator assembly was destroyed, but the bare capsule was recovered intact. Unit P-13 was subjected to a static overpressure of 1700 psig in an open-field test; the generator assembly was destroyed, and the bare, intact capsule, with some deformation on the side exposed to the blast and slight wrinkling of the clad, was recovered.

Capsules P-12 and P-13 from the overpressure test and heat sources P-15 and P-17 were used in the fragment tests of the sequential series. Fragment Test No. 1 was an impact of capsule P-12 by an electronic package weighing 38.75 lbs at 409 fps. The capsule was intact following the test, but the clad was breached, exposing the strength member. Capsule P-13 was impacted in fragment Test No. 2 by a flat sheet of titanium at 2100 fps. The only visual damage was some wrinkling of the clad due to flattening of the capsule. Fragment Test No. 3 was an edge-on titanium sheet fragment impacted at 495 fps into heat source P-17. The clad was torn open along the line of impact. Test No. 4 was an edge-on titanium sheet fragment impacted at 1700 fps into heat source P-15. The fragment was deformed by aerodynamic loading so that a curved edge impacted the capsule on the spherical end approximately 0.5 inch from the capsule end. The clad material was peeled back and the strength member was exposed and deformed in a circular crease about 2 inches long.

Capsule P-12, from fragment Test No. 1, and capsule P-19, a bare capsule, were then placed in a liquid propellant fire. The capsules were exposed to the thermal and chemical environment of burning JP-4 fuel for 34.5 and 33.6 minutes, respectively, in separate fires. The capsules were intact and experienced no visible damage from the tests. Capsules P-19 and P-12 were subjected to direct contact solid propellant fire tests for 4.75 minutes following the liquid propellant fire. The capsules were coated with residue from the fire. Posttest examination indicated the strength members and liners were breached.

Capsule P-15 from edge-on fragment Test No. 4 and heat source P-9 were subjected to a solid propellant double proximity fire test for 3.9 minutes. The test items were coated with residue from the fire. Visual examination indicated the units were intact.

After the proximity fire, units P-9 and P-15 were placed in a liquid propellant fire test; the test was identical to that given units P-12 and P-19. The burn time for the JP-4 fire was 33.5 and 36.0 minutes, respectively, for units P-9 and P-15. The test items were intact and experienced no visible damage from the tests.

All six of the test items from the launch abort sequential series were shipped to the Los Alamos Scientific Laboratory (LASL) for posttest examination and analysis of the fuel simulant response to the various environments.

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PIONEER RTG SAFETY EVALUATION:
PHASE I IMPACT AND LAUNCH ABORT SEQUENTIAL TESTS

INTRODUCTION

The Pioneer radioisotopic thermoelectric generator (RTG) is a system which utilizes the thermal energy from the decay of a radioisotope fuel to generate electric power. The system application is to provide electric power for the space craft on the Pioneer F and G planetary exploration missions to be conducted by the NASA.

As part of a test program to evaluate and qualify the Pioneer RTG heat source, Sandia performed several tests on the heat source in three configurations, i.e., as a bare capsule, inside a graphite heat shield, and assembled in the Pioneer generator housing. Sandia was designated the AEC contractor to perform these tests as part of the Sandia Laboratories Aerospace Nuclear Safety Department's support of the Pioneer program.

Test procedures for these tests were prepared by the Pioneer RTG systems contractor, Teledyne Isotopes. Representatives of NASA, U. S. Air Force, AEC, and Sandia ANS reviewed these plans at a joint meeting. Utilizing input from this critique, Teledyne Isotopes made the necessary revisions and issued the test procedures which defined the Pioneer RTG test program. Based on the requirements of this program, the Sandia test group prepared detailed test plans describing the manner in which the tests would be conducted. These plans were reviewed with Teledyne Isotopes and with their concurrence were used as the controlling documents in performing the test program.

These tests consisted of three impact tests to assess the correlation between the impact responses of the Pioneer and the Transit heat sources to similar conditions and a test series designed to simulate a launch abort sequence of environments. The impact tests were also used to evaluate the radioactive fuel containment integrity of the Pioneer capsule after a simulated earth impact. Units

P-8, P-10, and P-11 were impact tested, and the details of this series are described in the Phase I Impact Tests section of this report.

Sequential testing was utilized to investigate the cumulative effects of the launch abort environments, i. e., overpressure, fragments, and propellant fires. Figure 1 illustrates the sequential test matrix and test conditions of the Pioneer launch abort tests; Table I summarizes the test matrix and countdown and the results. The test details of this series are described in the Launch Abort Sequential Tests section of this report.

Figure 1. Launch abort sequential test matrix

TABLE I
Launch Abort Sequential Tests Summary

Unit No.	Overpressure Test	Fragment Test	Solid Propellant Proximity Fire Test TE-364 Propellant	Liquid Propellant Fire Test JP-4 Fuel	Solid Propellant Direct Contact Fire Test TE-364 Propellant
P-9			Time 3.95 min. Capsule intact	Time 33.5 min. Capsule intact	
P-12	Overpressure 305 psi. Impulse 1.7 psi sec Capsule intact	Telemetry Pack 409 fps Clad opened		Time 34.25 min. Strength member intact	Time 4.75 min. Capsule breached
P-13	Overpressure 1700 psi. Capsule intact	Flat sheet 2100 fps. Capsule intact			
P-15		Edge-on Sheet 1700 fps Clad breached	Time 3.95 min. Strength member intact	Time 36 min. Strength member intact	
P-17		Edge-on Sheet 495 fps. Clad breached			
P-19				Time 32.5 min. Capsule intact	Time 4.75 min. Capsule breached

The Pioneer test items consisted of a three layer capsule (Figure 2), either bare or encased in the heat shield or generator. Initially, all the capsules except P-19 were encased in a graphite heat shield. The capsule and heat shield comprise the heat source assembly and were fabricated as shown in Figure 3. However, the units for these tests had Poco AXM-5Q graphite in lieu of the Poco AXF-Q1 graphite used in the actual Pioneer flight hardware. The units did not have the pyrolytic graphite sleeves as shown, but they had the Poco AXM-5Q machined with extra thickness in that area to hold the capsule properly. The flight hardware no longer contains the TZM complaint cups and tantalum felt complaint pads; however, these were present in the test items used in the tests described in this report.

Two units, P-12 and P-13, tested in the launch abort sequential series were assembled in a Pioneer generator housing. These assemblies included thermo-electric couples, couple mounting plates, and the associated wiring and insulation to simulate an actual generator.

This test series was begun on July 25, 1970 and was completed on February 3, 1971. All tests were conducted using the environmental test facilities of Sandia Laboratories.

Figure 2. Pioneer fuel capsule

Figure 3. Pioneer heat source

PHASE I IMPACT TESTS

Objectives

The objectives of the Pioneer heat source impact tests were two-fold: (1) assess the correlation between the impact responses of the Pioneer and the Transit heat sources, and (2) evaluate the radioactive fuel containment integrity of the Pioneer capsule after a simulated earth impact.

Test Details and Procedures

The impact series was conducted using the "turn around" technique. With this technique, the test item is positioned in the desired impact attitude and the target is accelerated to the specified velocity and then impacts the test item. For these tests, each heat source was mounted on a specially prepared stand, positioned between the rocket sled tracks, and heated to the desired temperature (2400°F-strength member) by an overhead furnace which was lowered over the heat source. During the heating period an atmosphere of argon gas was maintained in the furnace to protect the unit from oxidation. The argon flow was regulated to 1 cfm by a flow meter. The desired impact velocity was 326 fps.

The heat sources were impacted by a two-foot cube of Escondido granite mounted with one face normal to the velocity vector. The units were protected from further impacts by a padded and insulated catcher box. The equipment and general arrangements used in the test series are shown in Figures 4 through 6.

Test Results

Pioneer heat sources P-8, P-10, and P-11 were impacted in this series. All three units were in the heat source configuration with graphite heat shields containing the fuel capsules. The impact of each unit was against the end of the capsule

Figure 4. Phase I impact test setup

Figure 5. Phase I impact test setup - 45°

Figure 6. Phase I impact test setup - 0°

containing the pressure relief device (PRD). The test conditions and results are summarized in Table II.

TABLE II
Impact Test Conditions

Unit No.	Impact Angle* (deg)	Velocity (fps)	Temperature (°F)	Results
P-8	45	324	2400	Cracked clad, strength member, and liner.
P-10	0	325	2400	Intact.
P-11	22.5	325	2400	Cracked clad, strength member, and liner.

*Impact angle is defined as the angle between the cylindrical axis of the capsule and the velocity vector of the target block.

Unit P-8 had two cracks in the clad material. One was located along the periphery of the primary impact area and exposed the strength member only. The second was located in the central position of the primary impact area and was approximately 3/4 inch long by 1/16 inch wide; both the T-111 strength member and the tantalum-10% tungsten liner were breached. This heat source had dropped out of the catch box into the water brake trough about 40 feet from the stopping point of the sled. A water sample was taken at the point of entry before the capsule was moved; there was no indication of simulant release. A "Kimwipe" used to handle the wet capsule was counted, and no counts above background were detected. Photographs of the impacted capsule P-8 are presented in Figures 7 and 8.

Unit P-10 was impacted at 0° (end-on) and had no visible cracks in the heat source. The heat source experienced significant deformation from the impact, and posttest examination revealed a leak in the "star" section of the clad. The volume of the impacted capsule was 308 cm³, indicating no significant volume change. Similar results were observed in end-on impacts of the Transit capsule. Photographs of the impacted capsule P-10 are presented in Figures 9, 10, and 11.

Figure 7. Capsule P-8 after impact

Figure 8. Capsule P-8 after impact

Figure 9. Capsule P-10 after impact

Figure 10. Capsule P-10 after impact

Figure 11. Capsule P-10 after impact

Unit P-11 had a crack approximately 1-1/4 inch long by 1/16 inch wide located centrally in the primary impact area. The crack extended through the clad, strength member, and liner. Health physics monitoring of the capsule gave no counts above background. Photographs of the impacted capsule are presented in Figures 12 and 13.

Figure 12. Capsule P-11 after impact

Unit P-10 was sent to Los Alamos Scientific Laboratory (LASL) for posttest sectioning and fuel simulant analysis. Units P-8 and P-11 were returned to the contractor, Teledyne Isotopes.

Figure 13. Capsule P-11 after impact

LAUNCH ABORT SEQUENTIAL TESTS

Overpressure Tests

Objectives

The objectives of the Pioneer overpressure tests were to investigate the response of the RTG/capsule to the predicted environments of a launch pad abort explosion. To accomplish this, overpressure tests were performed on two Pioneer RTG assemblies, units P-12 and P-13.

Test Details and Procedures

The overpressure tests were the first in the launch abort sequential series. Two test levels were specified: (1) a static overpressure of 320 psi and a static impulse of 1.98 psi-sec to simulate a reference launch abort explosion which is defined as the maximum realistic air burst of the Centaur; and (2) a static overpressure of 2200 psi and a static impulse of 0.35 psi-sec to simulate a maximum realistic launch abort explosion which is defined as fallback of the TE-364 at a velocity sufficient to produce a 20 percent yield. These test procedures are discussed separately because different techniques were utilized in their performance.

Nominal Launch Abort (Shock Tube Test) -- The nominal launch abort test was conducted in a shock tube on unit P-12. A shock tube was assembled specifically for this test and consisted of a 38.7 foot length of 6.5 feet inside diameter tube and three shorter lengths of 6 feet inside diameter tubes. The total tube length was 60.2 feet. The larger diameter tube served as a driver, and the generator was mounted 1.3 feet from the muzzle end (station 58.9) in a piece of the 6 foot tube. Figures 14 and 15 show the shock tube and installed generator.

A clam shell oven was used to heat the generator to the desired temperature of 325°F. The test item was maintained at this temperature for 30 minutes to assure that the unit temperature had stabilized. The oven was opened 15 seconds prior to the test and pulled from the tube by a winch mechanism. Figures 16 and 17 show the oven in its various positions.

Figure 14. Shock tube overpressure test setup

Figure 15. Shock tube overpressure test setup

Figure 16. Closed heater - shock tube overpressure test

Figure 17. Opened heater - shock tube overpressure tube

An explosive charge of five 20 pound cubes of TNT, uniformly spaced on a 1.0 inch thick steel plate, was used to generate the pressure wave in the tube. This charge holder and a 25,000 pound concrete tamper block comprised the breech of the shock tube. After the unit reached temperature and the oven was removed, the test was initiated by simultaneously detonating the five charges.

Maximum Realistic Launch Abort (Open Field Test) -- This test was conducted on unit P-13 as an open field blast. The site and test setup are shown in Figures 18 and 19, and pertinent features of the setup are identified. The generator was mounted on a support structure which simulated the actual support structure used to mount the generator to the spacecraft. The support structure was bolted to a 0.062 inch thick aluminum plate whose ends were folded at 90° and buried 24 inches below the earth's surface. A heater assembly consisting of a 1 kw heating element and an insulating shell was used to heat the generator to the specified temperature of 325°F.

The explosive charge for this test was a 466 lb., cast TNT hemisphere with a 15-inch radius. The separation distance between the generator centerline and the center of the flat surface of the charge was 57 inches. The test was initiated by detonating a C-4 booster located in the center of the base of the hemisphere.

Test Results

Test No. 1 was the nominal launch abort test performed in the shock tube. Unit P-12 was used in this test. The generator assembly and graphite heat shield were blown away in the test. The bare capsule was found at a distance of 160 feet and at an angle of 2° right of the centerline of the tube muzzle. The capsule experienced no visible structural damage and only minor loss of the platinized alumina emissive coating. Figure 20 shows the capsule as it was found after the test. The debris from the generator assembly was collected and is shown in Figure 21.

Shock properties, which were calculated from shock velocity at the leading edge* of the generator fins (58.1 feet downstream in the tube), were as follows:

Shock arrival time	8.45 msec
Shock mach no.	4.70
Flow mach no.	1.79
Static overpressure	305 psig
Stagnation overpressure	1403 psig
Dynamic pressure	662 psi
Static impulse	1.7 psi-sec

*Shock properties were calculated at this point rather than at the RTG centerline because of the anomalies that occur as the shock wave envelopes the RTG.

Figure 18. Open field overpressure test setup

Figure 19. Open field overpressure test setup

Test No. 2 was the maximum realistic launch abort test performed as an open field test. Unit P-13 was subjected to the overpressure environment of a detonating 446 lb charge of TNT. The generator assembly and graphite heat shield were destroyed in the test. The bare capsule was recovered intact from the earth berm. It has experienced some deformation on the side exposed to the blast, but it had no visible openings in the clad material. Figure 23 shows the generator debris recovered after the test.

Figure 20. Capsule P-12 after overpressure test

Figure 21. Debris -shock tube overpressure test

Figure 22. Debris - open field overpressure test

No direct measurement of either peak static overpressure or impulse was made at the test item location, so shock parameters were determined from the shock velocity for a radius of 57.5 inches, the separation distance between the generator and the center of the charge base. The calculated shock parameters are given below:

Shock mach No.	10.5
Static overpressure	1700 psig
Stagnation overpressure	12.7×10^3 psig
Reflected overpressure	17.2×10^3 psig

Fireball growth rate and luminosity measurements gave an estimated effective yield of 456 lbs $\pm$ 20 percent. This measurement technique, however, cannot determine if a portion of the explosive was a low order detonation.

Both capsules P-12 and P-13 continued in the sequential series to the fragment tests.

Fragment Tests

Objectives

The objectives of the Pioneer fragment tests were to investigate the response of the heat source/capsule when impacted by representative fragments that could be generated in a launch pad abort explosion of the Atlas/Centaur/TE-364 and to evaluate the capsules' fuel containment capability in this environment. To accomplish this, fragment tests were performed on capsules P-12 and P-13 and heat sources P-15 and P-17.

Test Details and Procedures

The fragment tests were conducted using a direct technique which simulates the actual conditions in a launch abort. The test items are mounted in the desired attitude on frangible stands. Representative fragments are accelerated to the specified velocity and impacted against the test item.

Three tests, the electronic package fragment and two edge-on sheet fragment impacts, were conducted on the 5000-foot track facility. A flat side-on fragment test was performed using a flyer plate technique. Thus, the fragment tests procedures are divided according to the technique used in their performance.

Electronic Package and Edge-On Fragment Tests -- For these tests, impact was accomplished by fixing and heating the test item in the path of the sled-borne fragment. The test setup is shown in Figure 23 for the electronic package test performed on capsule P-12. This capsule had previously been tested in a nominal launch abort overpressure test in the shock tube. Figure 24 shows a dummy electronic package mounted to the outrigger on the sled. The electronic package fragment used in the test is shown in Figure 25.

The electric heater was lowered over the test item to bring it to the specified temperature and lifted clear 9 seconds before impact. A sand bag catcher was built just behind the test item to minimize damage to the unit from secondary impacts.

To provide an inert atmosphere during the heating period, argon gas was piped through the heater floor and vented out the top of the heater. The flow was maintained at 1 cfm throughout the heating period. When the capsule reached temperature, the heater was raised and the test was initiated by firing the rocket motors mounted on the sled.

The test setup is shown in Figures 26 and 27 for the edge-on test performed on heat sources P-15 and P-17. The fragments used in these tests were 8 x 12 x 0.055 inch thick sheets of 6AL-4V titanium and weighed approximately 0.86 lb. The target velocity for this test was 1560 fps.

Flat Side-On Fragment Test -- This test was conducted at Sandia's 6710 firing site located in Area III. The impact was accomplished by explosively driving a 12 x 12 x 0.055 inch thick sheet of 6AL-4V titanium into the heated capsule. The test setup is shown in Figures 28 and 29 for the flat side-on test performed on capsule P-13. This capsule had previously been tested in a maximum realistic launch abort overpressure test in an open field experiment.

The explosive system to drive the fragment consisted of 0.070 inch of Detasheet "D", line wave generators, and SE-1 detonators. A blast shield was used to prevent as much of the explosive products as possible from following the fragment. The flyer fragment was mounted in a machined hole in the blast shield (Figure 30). The blast shield was tilted 6° so that the sweeping load of the explosive detonation would produce a vertical flyer plate at impact. To mitigate the pressure

Figure 23. Electronic package fragment and capsule

Figure 24. Sled and dummy fragment

Figure 25. Electronic package fragment

Figure 26. Fragment edge-on test setup

Figure 27. Fragment edge-on test setup

Figure 28. Flat side-on test setup

Figure 29. Flat side-on test setup

Figure 30. Fragment (flyer) in place in blast shield

transmitted from the explosive to the titanium sheet and thus prevent spallation of the fragment, a 0.5 inch thick piece of polyurethane foam was placed between the fragment and the explosive.

The capsule was suspended in the positioning frame on platinum wires and heated in an electric heater buried in the ground just in front of the blast shield. The capsule had experienced some deformation in the overpressure test. The capsule was positioned so that impact occurred on the undeformed side. Argon gas was piped into the heater to minimize oxidation of the capsule during the heating period. The open flow was regulated to 1 cfm by a flow meter. When the capsule reached the specified temperature of 1850°F and had been thermally soaked for 30 minutes, it was raised into test position by the positioning frame and the explosive system detonated.

Test Results

Fragment Test No. 1 was an impact of capsule P-12 by an electronic package weighing 38.75 lbs. The fragment was mounted so that it impacted the capsule along the leading edge of the fragment, a corner of the electronic package. The diagonal through the package from the impact edge to the rear corner was aligned with the velocity vector of the fragment.

The measured velocity of the fragment was 409 fps. The temperature of the capsule at impact was 1865°F. The capsule was intact following the test, but the clad was breached and the T-111 strength member was exposed. Figures 31 through 33 show the condition of the capsule following the test. The electronic package was destroyed in the test. Health physics monitoring of the capsule measured no radiation above background. Figure 34 shows the test site with some of the debris from the electronic package following the test. Capsule P-12 continued in the sequential series to a liquid fire test.

Test No. 2 was the flat side-on fragment test conducted with capsule P-13. A 12 x 12 x 0.055 inch thick 6AL-4V titanium fragment was explosively driven into the capsule. The velocity of the fragment, as measured by pin switches located in line with the leading edge of the capsule, was 2100 fps. The fragment struck the capsule at an angle of 2°23', or 0.25 inch out of flatness across a 12 inch dimension. The capsule temperature at impact was 1850°F. Motion pictures show that the capsule did not rotate after the fragment impacted, indicating a flat impact was achieved.

Figure 31. Capsule P-12 after fragment test

Figure 32. Capsule P-12 after fragment test

Figure 33. Capsule P-12 after fragment test

The capsule was recovered approximately 38 feet from the impact point. The only visual damage was some wrinkling of the clad due to flattening of the capsule. There were no apparent breaks in the clad. Health physics measured no radiation above background.

The fragment sheared around the capsule and broke into pieces which were located up to 300 feet from the impact point. Figure 35 shows the reassembled fragments. The fireball from the explosives obscured the photographic coverage of the impact, and therefore fragment velocity at impact was not obtained. Fragment parts 6 feet past the impact point were photographed, and their instantaneous velocity was determined to be 1800 fps.

Test No. 3 was an edge-on titanium sheet fragment test conducted on heat source P-17. The specified velocity was 1560 fps. The fragment used was a 8 x 12 x 0.055 inch thick 6AL-4V titanium sheet. Due to a rocket misfire, the velocity attained was 495 fps. The fragment impacted edge-on against the heat source with the fragment edge parallel to the cylindrical axis of the heat source. The temperature of the unit at impact was 1876°F.

Figure 34. Debris from electronic package fragment test

Figure 35. Posttest fragment

The clad tore open along the line of impact, and the strength member was exposed. The damaged capsule and recovered fragment pieces are shown in Figures 36 and 37. This was judged a no-test, and heat source P-15, a contingency unit in the fragment series, was put into Test No. 4 for a repeat of Test No. 3. Health physics monitored capsule P-17 and measured no radiation above background. This completed the testing of capsule P-17, and it was shipped to LASL for post test examination.

The measured velocity on Test No. 4 was 1700 fps. The fragment, an .8 x 12 x 0.055 inch thick 6AL-4V titanium sheet, was deformed by aerodynamic loading so that a curved edge impacted the capsule. Impact occurred on the spherical end approximately 1/2 inch from the capsule end. The clad material was peeled back, and an area approximately 1 x 1-1/2 inches of the strength member was exposed. The strength member was deformed in a circular crease about 2 inches long where the fragment edge impacted. Figures 38 and 39 show the impacted capsule. The capsule temperature at impact was 1310°F. Capsule P-15 continued in the sequential series to the solid fire proximity test.

Liquid Propellant Fire Tests

Objectives

The primary objective of the liquid propellant fire tests was to demonstrate the Pioneer isotopic fuel capsule containment capability when subjected to a fire that simulated burning of the residual fuel after an on pad abort explosion of the Atlas launch vehicle. A secondary objective of the liquid fire tests was to evaluate the heat flux and temperature profile of the thermal environment in the vicinity of the test specimens.

Test Details and Procedures

The liquid propellant fire tests were conducted at the Lurance Canyon firing site of the Sandia Coyote Test Field. A burn pit approximately 15 feet square and 24 inches deep was excavated and lined with plastic sheets to contain the fuel. The fuel used for these tests was JP-4. The bottom of the burn pit was covered with 3 or 4 inches of water which provided a level surface on which the JP-4 floated.

Figure 36. Capsule P-17 after fragment test

Figure 37. Capsule P-17 after fragment test

Figure 38. Capsule P-15 after fragment test

Figure 39. Capsule P-15 after fragment test

Approximately 8.25 inches of JP-4 fuel was used to give the required burn time of 33 minutes. A copper calorimeter with two chromel/alumel thermocouples installed was positioned 30 inches above the initial fuel level. The surface of the calorimeter was blackened with sulfurated potash. Two chromel/alumel thermocouples were positioned at 20 inches and 30 inches above the initial fuel surface. These thermocouples were held in position in a small column of concrete with the couple junction ends extending approximately one inch above the top. The thermocouple leads were protected by running them underground out beyond the pit sides. The capsule was suspended 24 inches above the initial fuel level in a stainless steel basket lined with platinum strips to prevent possible material interaction of the capsule and basket. The capsule was preheated and soaked for 45 minutes at a temperature of 1850°F in an argon atmosphere furnace located to one side of the burn pit. The soak period was to insure a uniform temperature throughout the capsule. The capsule was then moved from the furnace to the center of the fire pit on a trolley mechanism. Figure 40 is a view of the burn pit with the capsule in position.

The calorimeter and thermocouple data were recorded continuously on a drag-pen type recorder. The wind velocity was measured in the immediate area by an anemometer and was recorded continuously. Documentary film coverage was provided by two 16 mm cameras positioned to document movement of the capsule from the furnace to the burn pit center and to provide a field of view of the entire test.

The JP-4 fuel was ignited with electric matches located at the center of two sides of the burn pit. The duration of the fire was timed by an observer with a stop watch. Documentary still photographs and x-rays of the posttest capsules were made.

Test Results

Test Unit P-19 -- The configuration of this unit was a bare capsule. It was selected as the unit to be subjected to a liquid fire environment and then used in the solid propellant direct contact fire test.

The capsule was heated to 1875°F and allowed to soak for 45 minutes at this temperature. This temperature was 25°F above the required 1850°F to allow for cool down of the capsule while transporting it from the furnace to the burn pit. Transport time was 10 seconds.

Figure 40. Pioneer liquid fire test setup

The ambient temperature at the time of the test was 40°F. The fire duration was 33 minutes and 35 seconds. Calorimeter data as shown in Figures 41 and 42 indicate TC No. 1 functioned for approximately 10 minutes. TC No. 2 functioned for a little over 20 minutes. The heat flux calculated for the calorimeter was 6.29 BTU/ft²-sec-°F.

The data indicate that the TC positioned 20 inches above the initial JP-4 surface (Figure 43) operated for only 1 minute; however, the data look realistic. The maximum temperature recorded was 1780°F. The data from the TC positioned 20 inches above the initial TP-4 surface (Figure 44) indicate the TC operated for only 1 minute, and the maximum temperature indicated was approximately 1680°F. The wind velocity data (Figure 45) shows the velocity at the start of the test to be approximately 2 mph increasing to a maximum of a little over 12 mph toward the end of the test.

A posttest visual inspection of the capsule revealed no damage. The surface was blackened from the fire. Health Physics monitoring measured no counts above background.

Test capsule P-19 was retained at Sandia for the solid propellant contact fire test.

Test Unit P-12 -- Test unit P-12 was one of the units selected for sequential testing. The configuration of this test unit was a bare capsule. The previous over-pressure test had removed the generator housing and the graphite heat shield, and the electronic package fragment test resulted in the capsule platinum clad being breached.

The capsule was heated to 1870°F and allowed to soak for 30 minutes at this temperature. This temperature was 20°F above the required 1850°F to allow for capsule cool down in transporting it from the furnace to the burn pit. Transport time was 7 seconds.

Ambient temperature at the time of the test was 40°F. The fire duration was 34.5 minutes. Calorimeter data (Figures 46 and 47) indicate an early malfunction of TC No. 1 and TC No. 2 operating for only over 2 minutes. The TC positioned 20 inches above the initial JP-4 surface functioned properly for about half the fire duration. The maximum temperature recorded (Figure 48) was 1790°F.

Figure 41. P-19 bare capsule liquid fire test

Figure 42. P-19 bare capsule liquid fire test

Figure 43. P-19 bare capsule liquid fire test

Figure 44. P-19 bare capsule liquid fire test

Figure 45. P-19 bare capsule liquid fire test

Figure 46. P-12 recorder No. 1

Figure 47. P-12 recorder No. 1

Figure 48. P-12 recorder No. 2

The TC positioned 30 inches above the initial JP-4 surface functioned for only one minute. The maximum temperature recorded (Figure 49) was 1890°F. The recorded wind velocity (Figure 50) varied between 2.5 and 7.5 mph for the test duration.

A posttest visual examination of the capsule revealed that the strength member had experienced some oxidation in the area that had been exposed, i. e., the area where the clad was breached in the fragment test. Health Physics monitoring measured no counts above background. Figure 51 is an x-ray view of the posttest capsule. Figure 52 is a posttest view of the capsule immediately after the test.

Capsule P-12 was held at Sandia for the next sequential test which was the solid propellant direct contact test.

Test Unit P-9 -- Test unit P-9 was a heat source that had previously been subjected to the solid propellant proximity test. The graphite heat shield was heavily coated on four of the six sides with the solid propellant fire residue, primarily aluminum and aluminum oxide. The residue on the two uncoated sides were removed before the test.

The heat source was preheated to a temperature of 1325°F and soaked for approximately 30 minutes. The fire duration was 34.5 minutes. The thermocouples mounted 20 inches and 30 inches above the initial liquid propellant surface indicated a maximum temperature of 1480°F and 2030°F respectively. Figures 53 and 54 are graphic presentations of the thermocouple data. Only one of the calorimeter thermocouples was functioning at the start of the test. Calorimeter No. 3 (Figure 55) data are shown in Figure 56. The calculated heat flux for this test was 8.2 Btu/ft² sec°F. The wind velocity for this test was between 7.5 and 19 mph; wind velocity data are shown in Figure 57.

A posttest visual examination of the heat source revealed no significant damage to the graphite heat shield; there was some oxidation of the bare graphite surfaces, approximately 1/3 the initial thickness (Figure 58).

Health Physics monitoring measured no counts above background. The graphite heat shield was removed from the capsule and it was given to the Isotopes representative for return to Isotopes for their evaluation. Only a slight discoloration of the capsule was noted, and this undoubtedly resulted from the solid fire test not from the liquid fire.

Figure 49. P-12 recorder No. 2

Figure 50. P-12 recorder No. 2

Figure 51. X-ray of P-12 after liquid fire test

The capsule was shipped to LASL for postmortem evaluation.

Test Unit P-15 -- Test unit P-15 was a bare capsule that had previously been through the edge-on fragment test, which resulted in peeled cladding on one end, and the solid propellant proximity fire test. The strength member had experienced some melting in the area where the clad had been peeled, and the unit was heavily coated with residue from the solid propellant fire.

The fire duration was 36 minutes. The thermocouples mounted 20 inches and 30 inches above the initial liquid propellant surface indicated a maximum temperature of 1920°F . The 30 inch thermocouple failed to function properly. Figures 59 and 60 are graphic presentations of the thermocouple data. Calorimeter No. 3 (Figure 55) thermocouple data are presented in Figures 61 and 62. The calculated heat flux for this test was $6.2 \text{ Btu/ft}^2\text{-sec}^{\circ}\text{F}$. The wind velocity for this test was between 4.5 and 15.2 mph; wind velocity data are shown in Figure 63.

A posttest visual examination of the capsule revealed no further damage as a result of this liquid fire environment (Figures 64 and 65). There was, of course, no way to determine how much, if any, oxidation had resulted from this test.

Health Physics monitoring measured no counts above background.

The capsule was shipped to the LASL for postmortem evaluation.

Figure 52. Pioneer capsule P-12 after liquid fire posttest

Figure 53. P-9 liquid propellant test

Figure 54. P-9 liquid propellant test

Figure 55. Copper calorimeter

Solid Propellant Direct Contact Fire Tests

Objectives

The primary objective of these tests was to determine the resistance of the Pioneer capsule to a solid propellant (Thiokol TP-H3062) fire environment. A secondary objective was to measure the heat flux of this flame.

Test Details and Procedures

The solid propellant fire tests were conducted at the Lurance Canyon firing site of the Sandia Coyote Test Field. The solid propellant used for these tests was Thiokol TP-H3062 propellant which is the fuel for the TE364-4 rocket motor. The sample propellant blocks were 12 inches wide by 18 inches in length by 12 inches thick and each had flame inhibitor on all except the burn surface.

The furnace used to preheat the test items provided an argon atmosphere. The furnace heating elements were bayonet type Glo-bars (silicon carbide heaters).

Figure 56. P-9 liquid propellant test

Figure 57. P-9 liquid propellant test

Figure 58. Pioneer heat source P-9 after liquid propellant fire test

Figure 59. P-15 liquid propellant fire test

Figure 60. P-15 liquid propellant fire test

Figure 61. P-15 liquid propellant fire test

Figure 62. P-15 liquid propellant fire test

Figure 63. P-15 liquid propellant fire test

Figure 64. Pioneer capsule P-15 after liquid propellant fire test

Figure 65. Pioneer capsule P-15 after liquid propellant fire test

A copper calorimeter was used in each of the fire tests to measure the heat flux. The exposed calorimeter surfaces were blackened with sulfurated potash to present a near black body to the flame. The calorimeters were instrumented with two stainless steel sheathed, ungrounded, chromel/alumel thermocouples. The TC leads were protected with a stainless tube in a sleeve of graphite with an exterior wrapping of asbestos tape. Calorimeter data were recorded continuously on a drag pen type recorder.

Pyrometric photography and documentary 16 mm film coverage was employed on each of the solid propellant fire tests. For the direct contact tests, the calorimeter was placed on the propellant surface as part of the initial setup. The TC lead wires, with the protective sleeving, were mounted in a manner to allow the calorimeter to settle with the burning propellant surface, thus remaining in contact for the test duration.

Test Results

The first of the direct contact solid propellant fire tests was performed with capsule P-19. This unit had previously been exposed to the liquid fire test.

As a result of a malfunction of the trolley transport mechanism, which moved the capsule from the furnace to the propellant block, this test was not successful. The trolley failed to stop in the correct position and knocked the calorimeter off the edge of the propellant block. When the capsule platinum suspension wires gave way, the capsule dropped close to the end of the propellant block and also fell off. The fire duration was 4 minutes and 35 seconds. The capsule and the calorimeter experienced only partial exposure to the fire environment. The calorimeter data were therefore not good. The end of the capsule which landed next to the propellant block did experience enough exposure to the fire to melt a small area (Figure 66). Figure 67 is a close up view of the melted area. A post test x-ray of this capsule revealed that the clad material had melted through in this area with only slight melting of the strength member. After viewing the x-ray, it was decided that P-19 could be used in the next direct contact test. Pyrometric photography data are presented in Figure 68.

The second direct contact solid propellant fire test was performed with capsules P-12 and P-19. P-12 was a sequential test unit that had previously been exposed to, in order, the low overpressure shock tube test, the electronic package fragment

Figure 66. Pioneer capsule P-19 after solid fire direct contact test 1

Figure 67. Pioneer capsule P-19 after solid fire direct contact test 1

test, and the liquid propellant fire test. The fragment test resulted in minor deformation of the capsule and a breach of the clad. Some oxidation of the strength member was observed in the area of the breached clad after the liquid fire test. P-19 had been exposed to a liquid fire test and was in the first unsuccessful direct contact solid propellant test.

The capsules were preheated to a temperature of 1870°F and allowed to soak at this temperature for 45 minutes. Transportation time from the furnace into position over the block was 10 seconds. The propellant was ignited by black powder which in turn was ignited with an electric squib. The duration of the fire, as timed by an observer with a stop watch, was 4 minutes and 45 seconds. Health Physics monitoring measured no counts above background. Calorimeter No. 6 (Figure 55) thermocouple data (Figures 69 and 70) indicate the TC's operated for about 4 minutes and 29 seconds. The calculated heat flux was determined to be 68.2 Btu/ft²-sec°F. A posttest examination of the fire pit revealed that the copper calorimeter had almost completely melted and the capsules were frozen in the solidified copper. The capsules were covered with residue products from the burning propellant. Figure 71 is a side view of the test units. Figure 72 shows the areas where it appears the fuel containment was breached. Pyrometric photography data is presented in Figure 73. A final determination as to whether the capsules were breached will be made in a postmortem examination which is to be performed by LASL.

Figure 68. Pyrometric photography data, unit P-19

Figure 69. Recorder No. 1 - direct contact fire test

Figure 70. Recorder No. 1 - direct contact fire test

Figure 71. Pioneer capsules P-12 and P-19
after solid fire direct contact test 2

Figure 72. Pioneer capsules P-12 and P-19
after solid fire direct contact test 2

Figure 73. Direct contact solid fuel burn test pyrometric photography data

TABLE III

Results of Solid Propellant Direct Contact Fire Tests

<u>Test Unit No.</u>	<u>Test Configuration</u>	<u>Propellant (TE364-4) fuel</u>	<u>Fire Duration</u>	<u>Test Results</u>	<u>Pyrometric Photo Temps. (°F)</u>
P19	New Bare Capsule	TP-H3062	4 min. 35 sec.	Unit fell off propellant block	2499
P12 & P19	Bare Capsules	TP-H3062	4 min. 45 sec.	Visually both capsules ap- peared breached	3880

Double Proximity Propellant Fire Test

Objectives

The test objectives of the double proximity propellant fire test were the same as those of the solid propellant direct contact fire tests described above.

Test Procedures and Details

Two blocks of the TP-H3062 propellant were used for the double proximity test. The blocks were placed directly on the ground, eight inches apart, with the uninhibited burn surfaces of the propellant blocks facing each other. Just below ground surface and in the 8 inch space between the propellant blocks a high temperature concrete track was constructed. This track was used to guide a small four-wheel cart, carrying the test units, from the preheating furnace to the desired position between the blocks of propellant.

The copper calorimeter No. 4 (Figure 55) for this test was placed on the ground between the propellant blocks as part of the initial setup. The calorimeter was oriented in what could be considered an inverted position with the leads down and extended underground for protection from the fire environment.

Test units P-15 (a bare capsule which, as a result of the previous edge-on fragment test, had the clad torn on one end) and P-9 (a new heat source consisting of a capsule inside the graphite heat shield) were placed on the transport cart (Figure 74). The bare capsule (P-15) was set in a horizontal position, and the heat source (P-9) was set on end. The cart, with the two test units on board, was rolled into the furnace (Figure 75). The test units were heated to a temperature of 1325°F and soaked at this temperature for 30 minutes. The two test units were then transported, on the cart, to the desired position between the propellant blocks. The propellant was ignited with black rifle powder which in turn was ignited with electric squibs.

Test Results

The duration of the double proximity propellant fire was 3 minutes and 57 seconds as timed by an observer with a stop watch. Figure 76 shows the test setup after the fire. A posttest visual examination revealed no damage to heat source P-9.

Figure 74. Transport cart with capsule and heat source on board between blocks of propellant - calorimeter in place

Figure 75. Transport cart, with capsule and heat source on board, in preheating furnace

The graphite heat shield appeared in good condition, with deposits of aluminum and aluminum oxide up to 1/4 inch thick covering the surfaces that were exposed directly to the fire (Figure 77).

A posttest visual examination of the bare capsule P-15 revealed some melting of the strength member in the area where the clad had been torn away (Figure 78). The extent of the melting could not be determined.

Pyrometric photography isodensity data are presented in Figure 79. The calorimeter thermocouples functioned for approximately 4 minutes. The calculated heat flux was determined to be $65.6 \text{ Btu/ft}^2\text{-sec}^\circ\text{F}$.

Both test units were retained at Sandia for the follow-on test which was the previously described liquid propellant fire test.

Figure 76. Undisturbed posttest double proximity solid propellant fire test

Figure 77. Pioneer heat source P-9 double proximity solid propellant fire test

Figure 78. Pioneer capsule P-15 after double proximity solid propellant fire test

Figure 79. Double proximity solid fuel burn test pyrometric photography data

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