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**Safety Test No. S-6,
Launch Pad Abort Sequential Test Phase II:
Solid Propellant Fire**

by

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SAFETY TEST NO. S-6, LAUNCH PAD ABORT SEQUENTIAL

TEST PHASE II: SOLID PROPELLANT FIRE

by

E. C. Snow

ABSTRACT

Phase II of the S-6 test consisted of two solid propellant fire tests. Both tests were single proximity with a 0.914-m (3-ft) cube of UTP-3001 solid propellant inhibited on five sides. In both tests, the propellant cube was burned on a sand pad with the uninhibited surface vertical and the test specimens placed within a few centimeters of this burning surface. Steel was introduced into both tests via a 9.5-mm (3/8-in.) thick steel plate placed on top of the propellant cube prior to ignition.

The test specimen for the first test was an FSA with an Ir PICS and a thorium simulant fuel sphere. This specimen was preheated to approximately 1040°C, placed next to the propellant surface and the propellant ignited. Both the GIS and the PICS survived the fire with little or no damage. The only effect on the GIS was a slight erosion of the graphite fibers by the steel. The damage to the PICS consisted mainly of alumina and silica deposits on the surface. Neither the GIS nor the PICS was breached and no thorium was released.

The test specimen for the second burn was a mockup of a damaged HSA, consisting of a simulant filled 8-pack inside pieces of the graphite aeroshell encased in the remains of the Ir outer clad from the Phase I HSA impact test. Only four of the PISA's had Ir PICS, the other four were unclad thorium spheres. The specimen was preheated to a PICS temperature of approximately 980°C (1040°C oven temperature), placed next to the uninhibited surface of the propellant and the propellant ignited. Though part of the Ir outer clad was consumed, all of the GIS's and Ir PICS were intact and no thorium was released from the Ir clad PISA.

1.0 INTRODUCTION

In preparation for the Lincoln Laboratory's LES 8/9 space mission, a series of tests was performed to evaluate the nuclear safety capability of the Multi-Hundred Watt (MHW) Radioisotope Thermoelectric Generator (RTG) to be used to supply power for the satellite. One such safety test is Test No. S-6, Launch Pad Abort Sequential Test. The objective of this test was to subject the RTG and its com-

ponents to the sequential environments characteristic of a catastrophic launch pad accident to evaluate their capability to contain the $^{238}\text{PuO}_2$ fuel. This sequence of environments was to have consisted of the blast overpressure and fragments, followed by the fireball, low velocity impact on the launch pad, and solid propellant fire. The blast overpressure and fragments were subsequently eliminated from this sequence.

This report describes the procedures and presents the results of Phase II of Test S-6, Solid Propellant Fire. In this phase of the test, a simulant Fuel Sphere Assembly (FSA) and a mockup of a damaged Heat Source Assembly (HSA) were subjected to single proximity solid propellant fires of approximately 10-min duration. Steel was introduced into both tests to simulate the effects of launch pad debris and the solid rocket motor (SRM) casing that might be present in the fire zone.

The rationale for using these two test specimens is based on the results of Phase I of Test S-6, Low Velocity HSA Impact.¹ In that test, a simulant HSA was impacted on a concrete pad at approximately 30 m/s (≈ 100 fps). As a result of that impact, the HSA was badly damaged, with two FSA's being released. However, all of the Graphite Impact Shells (GIS's) were intact. It was, therefore, concluded that the most likely contact with burning solid propellant would be by an intact FSA rolling away from the HSA impact or the HSA itself impacting next to a piece of burning propellant. The fact that the HSA impact was almost inelastic would indicate that it is highly unlikely that either the HSA or one of the FSA's would ever end up on top of a piece of burning propellant. The small amount of dispersion observed in Phase I¹ would tend to suggest that the double proximity is also very unlikely. Therefore, it was decided that the fire tests would be of the single proximity type with a 0.914-m (3-ft) cube of solid propellant, simulating the full web thickness of a SRM, and involve an intact simulant FSA and a damaged HSA.

2.0 TEST DESCRIPTION

2.1 Propellant

The solid propellant used was UTP-3001 which is used in the SRM boosters of the Titan III C vehicle on which the LES 8/9 spacecraft will be launched. UTP-3001 contains powdered aluminum and ammonium perchlorate dispersed in a rubber binder. Several other additives are present in

small percentages. The propellant blocks were inhibited so as to burn only on one face to give the maximum burning time. The 0.9-m (3-ft) dimension corresponds to the web thickness of the Titan III C SRM's. The rationale is that a piece of an actual motor could not burn any longer than the time necessary to burn through a full web thickness. The steel plate was added to the test because the actual SRM's have a steel casing and it is thought by some that a rocket abort or destruct could not produce a large piece of solid propellant without having steel casing attached. In a previous fire test² it appeared that steel introduced into the fire might have been the cause of observed fuel containment failure.

2.2 FSA Fire Test

2.2.1 Test Specimen. The FSA used in this fire test was MHT-55, made up of a thoria (76% TD) simulant fuel sphere, a type WC Ir Post Impact Containment Shell (PICS), and a flight quality Graphite Impact Shell (GIS). This was one of the FSA's that was used to make up the "bottom" 8-pack of the HSA used in the Phase I impact test. A photograph of the Post Impact Sphere Assembly (PISA) from this FSA, taken after the Phase I impact but before the fire test, can be seen in Fig. 2.1. The only damage suffered by this PISA during the Phase I test is the dent shown in the photograph. This PISA was placed in a GIS and preheated to approximately 1040°C prior to being placed next to the uninhibited surface of the solid propellant.

A second FSA, MHT-43, was equipped with a thermocouple to measure PICS temperature and placed near the burning surface of the propellant prior to ignition. This FSA was not preheated and was used only as a part of the temperature measuring device.

2.2.2 Test Setup. The FSA fire test was set up at the LASL K-Site facility. A sand pad, approximately 3-m (9-ft) in diameter and about 0.3-m (1-ft) thick was constructed in an open area just to the east of the drop tower used in the Phase I test.

The 0.9-m (3-ft) cube of UTP-3001 solid propellant was placed near the center of the sand pad with one uninhibited surface down, so that the uninhibited surface was vertical and facing the northwest. A piece of steel plate, 9.5-mm (3/8-in.) thick, was placed on top of the propellant block with a few centimeters of the plate protruding over the uninhibited surface.

A tube furnace, equipped with a remotely operated trap door, was suspended on a tripod, so that the FSA could be preheated and then placed near the uninhibited surface of the propellant. A ramp, made of wood, was used to get the heated FSA from the furnace to a position near the propellant surface. The complete test setup can be seen in Fig. 2.2. Also shown in the figure are the relative positions of the two FSA's just prior to propellant ignition. The FSA in the foreground is the preheated test specimen, MHT-55, and the other is the non-preheated instrumented FSA, MHT-43. Just prior to ignition, the tube furnace and ramp were to have been pulled out of the fire zone by a cable attached to the lift at the drop tower (not shown in Fig. 2.2). Once the furnace and ramp were clear, the propellant was to have been ignited by smokeless powder, kerosene-soaked excelsior, and electrically fired squibs placed at the base of the uninhibited surface.

The FSA, MHT-43, was equipped with a tungsten-rhenium thermocouple with the temperature measuring bead against the PICS. This FSA was placed near the base of the propellant, just prior to ignition with the thermocouple bead on the side of the PICS away from the fire, but was not preheated. The thermocouple leads were passed through a small hole in the GIS and under the sand of the pad. Away from the pad, the leads were covered with enough sand to insure that they would not be burned during the test. The thermocouple was connected to a recorder and its output was monitored throughout the burn.

2.2.3 Test Operation. The FSA fire test was conducted on the morning of September 10, 1974, at the LASL K-Site facility. The weather was clear,

the temperature was about 20°C (68°F), and the winds were out of the northeast at 0.8 to 4.5 m/s (2 to 10 mph). During the test, the wind shifted to the east, but the velocity remained below 4.5 m/s.

At 7:40 A.M., the test FSA, MHT-55, was placed in the tube furnace, the trap door closed, and the furnace power turned on. At that time, the furnace, ramp, and block of propellant were all in place on the sand burn pad. While the preheat of the test FSA was in progress, the instrumented FSA, MHT-43, was placed near the base of the uninhibited surface of the propellant, the thermocouple installed, and the thermocouple leads covered with sand to protect them from the fire. At 9:10 A.M., when the furnace temperature was approximately 800°C, the flow of inert gas into the furnace was initiated and continued through the remainder of the preheat cycle. At 10:11 A.M., the furnace temperature had reached 1040°C. It was maintained at this temperature for the next 45 min prior to the test.

With everything in place and ready, the train of smokeless powder and the kerosene-soaked excelsior were placed at the base of the uninhibited face of the propellant cube. The squibs were also placed in the smokeless powder at that time, but were not wired to the firing circuit until just before the time of ignition.

At 10:50 A.M., all but the firing crew entered the control bunker. When the area was clear, the firing crew connected the squibs to the firing circuit and retired to the control bunker. At 10:54 A.M., the cameras, setup to photograph the burn from three different points, were turned on as was the recorder for the thermocouple in MHT-43.

At 10:55 A.M., the furnace was turned off and the trap door opened, allowing the preheated FSA to fall onto the ramp and roll up against the uninhibited surface of the propellant. The hot FSA ignited the propellant and the entire face was burning in less than two seconds. Since ignition had been achieved with the hot FSA, the squibs were not needed. The test was contained until all the propellant in the 0.9-m (3-ft) cube was exhausted.

2.2.4 Results. The burn lasted for approximately 9 min, sending a thick column of white smoke some 100 m into the air. The photograph in Fig. 2.3 gives some idea of the density and height of the smoke column. The tower that can be seen, engulfed in smoke, is about 58 m (191 ft) above the sand burn pad.

The control bunker can be seen in the lower right corner of Fig. 2.3. One of the cine-cameras used to take motion pictures of the burn was on top of that bunker. The other two were at the base of the tower.

After the burn, the area was monitored for thoria and none was found. Figure 2.4 is a photograph taken after the burn from almost the same position as that shown in Fig. 2.2. The blackened area was just behind the original position of the propellant cube and was probably the result of the inhibitor on the back of the propellant falling off and burning near the end of the test. The tripod on which the furnace was mounted was pulled away, but the furnace dropped onto the wooden ramp and melted into the light colored mass that can be seen at the left edge of Fig. 2.4. The track in the sand from the burn area to the lower right corner of the photograph was made by the leg of the tripod as it was pulled away. Since this leg was sitting at the front edge of the propellant block prior to the burn, it gives an indication as to where the two FSA's are located in relation to the fire debris shown in Fig. 2.4.

Figure 2.5 is a close-up of the burn area taken from the opposite side from that shown in Fig. 2.4. The positions of the two FSA's are indicated on the photograph but the FSA's themselves cannot be seen. The position of the remains of the steel plate can also be seen in the figure.

When the sand of the burn pad had cooled down, the two FSA's were recovered from the debris and found to be completely intact, though covered by the remains of the steel plate. The GIS of MHT-55 had been slightly eroded by the molten steel, but there was little evidence of any significant ablation

of the graphite on either GIS. A check for thoria showed no contamination on either GIS. Both FSA's were then removed to CMB-5 for photographing and a posttest examination.

The temperature-time history of the thermocouple on the PICS of MHT-43 is given in Fig. 2.6. Though the thermocouple failed about five minutes into the burn, a projection of the curve would indicate a maximum PICS temperature of approximately 1650°C (3000°F). The large dip in the curve was probably caused by the steel plate falling on the FSA at about 3.5 min into the burn. The reason for the thermocouple failure was the melting of the alumina insulation on that portion of the leads exposed between the GIS and the sand of the pad. Apparently, when the steel plate dropped on the FSA, this portion of the alumina insulator was exposed to the fire. The melting point of pure alumina is >2000°C.

2.3 HSA Fire Test

2.3.1 Test Specimen. The test specimen for this burn was a simulant filled mock-up of a damaged HSA, consisting of one 8-pack, pieces of the aeroshell, and part of the outer Ir clad. The 8-pack was constructed from the GIS's, retaining ring, and locking bolt of the intact 8-pack from the HSA used in the Phase I impact test. The 8-pack as it appeared after that test is shown in Fig. 2.7. This 8-pack was disassembled, the GIS's opened, and the T-111-clad PISA's removed. Four of these PISA's were stripped of the T-111 clad and the unclad thoria put back into the GIS's to be used as thermal simulants in the HSA mock-up. The other four PISA's were replaced with PISA's clad in Ir. When the test 8-pack was reassembled, three of the FSA's with Ir clad PISA's were placed so that they would be next to the burning propellant during the test. The fourth FSA with an Ir PICS was equipped with a thermocouple to monitor the PICS temperature during the preheat cycle and placed in the bottom layer of spheres, away from the flame front. The relative location of these four Ir FSA's and the four FSA's with unclad thoria simulant is shown in Fig. 2.8.

Once the 8-pack was assembled, it was placed in the remains of the Ir outer clad from the Phase I drop test, shown in Fig. 2.9. The relative positions of the Ir can, FSA's, and flame front are also indicated in Fig. 2.8. With the 8-pack in place, the Ir can was cut off above the top layer of FSA's. Pieces of the remains of the POCO aeroshell from the Phase I test were placed around the 8-pack, filling the void between the retaining ring of the 8-pack and the outer clad. The missing panel, shown just to the left of the rest of the can in Fig. 2.9, was cut to fit into the space that it had originally occupied. This panel, along with the others, was then slightly bent over the top of the 8-pack and a piece of the end crush-up was placed on top of the 8-pack. The whole assembly was then wrapped with two pieces of stainless steel wire to hold it together until the time of the test. Unfortunately, there are no photographs of the final mock-up available.

2.3.2 Test Setup. The HSA fire test was setup at the LASL K-Site facility. A sand pad, similar to that described above for the FSA fire test, was constructed in the same location. A 0.9-m (3-ft) cube of UTP-3001 solid rocket propellant was placed near the center of the pad with one inhibited surface down, so that the uninhibited surface was vertical and facing the northwest. A piece of 9.5-mm (3/8-in.) thick steel plate was placed on top of the propellant block, as before.

An oven was designed and built at LASL to fit over the specimen and to preheat it to about 1040°C. The oven, shown in Fig. 2.10, contained four heater elements and was designed so that when the specimen was sitting on an insulated pad, it would be located near the center of these four heater elements. The oven was also equipped to maintain an inert atmosphere in the oven cavity during the preheat cycle. The oven was mounted on a stand, which can also be seen in Figs. 2.10 and 2.11, so that it could be raised from the specimen and then pulled away, together with the stand, to a safe distance from the propellant prior to ignition. The cable used for this

operation can be seen in the foreground of Fig. 2.10.

Another cable, which can be seen stretched between the base of the propellant block and the oven in Fig. 2.11, was threaded under the propellant and used to pull the specimen to within a few centimeters of the uninhibited surface. This cable was attached to the base of the HSA mock-up by a thin stainless steel band.

A tungsten-rhenium thermocouple in a protective graphite tube was placed in the sand at the base of the propellant so that the recording end of the thermocouple would be very near the burning surface at ignition. The graphite tube was also equipped with an inlet to allow the cavity in the tube to be purged with argon just prior to ignition. A strip chart recorder was connected to the thermocouple so that the temperature could be recorded continuously during the burn.

2.3.3 Test Operation. The HSA fire test was conducted at the LASL K-Site facility on March 24, 1975. The weather that morning was mostly clear and cold with winds out of the west at about 8.9 m/s (20 mph). The air temperature was approximately -7°C (20°F) at the start of the preheat cycle and reached only -4°C (25°F) by the time of the test.

On the morning of the test, the propellant cube, steel plate, preheat oven, and test specimen were all in place. At 8:00 A.M., the preheat oven power was turned on and the preheat cycle started. At 9:00 A.M., the oven temperature had reached 1030°C (1900°F), but the PICS temperature was only 750°C (1382°F).

While the preheat continued, the tungsten-rhenium thermocouple was placed at the base of the uninhibited surface of the propellant block and connected to the recorder. A flow of argon to the protective graphite tube was established at that time, and allowed to continue until a few minutes before the test.

At 10:40 A.M., the temperature of the PICS in the test specimen was approximately 980°C (1796°F). Kerosene-soaked excelsior was placed along the base

of the uninhibited surface of the propellant and squibs were placed in the excelsior as a back-up in the event that the hot HSA failed to ignite the kerosene.

At 10:47 A.M., all visitors had been escorted to the viewing area, the squibs connected to the firing circuit, and all personnel moved to the control bunker. At 10:51 A.M., the oven was raised from the mock-up HSA, the stand and oven pulled over and dragged away from the fire zone. The test specimen was then pulled into position at the base of the propellant block. The kerosene-soaked excelsior was immediately ignited by the hot HSA. The propellant, however, did not ignite for about 10 s after the ignition of the excelsior. The entire surface of the propellant was engulfed in flame in less than a second after ignition of the propellant itself. The test was continued until all the propellant was exhausted.

Shortly after the test, the area was monitored for thoria and none was found. Later, after sufficient time for the sand and specimen to cool, the specimen was photographed, examined visually, and removed to CMB-5 for a posttest examination and additional photography.

2.3.4 Results. The burn lasted about 8 min from the time of ignition until the propellant was exhausted. This was on the order of 1 min shorter than the total burn time of the previous test with a cube of solid propellant having the same dimensions.

This reduction in total burn time was most likely caused by the strong winds out of the northwest that blew onto the burning surface. With the wind from that direction, the flames tended to be whipped around the back of the propellant and probably melted the inhibitor off the back and sides of the cube, thus allowing the back sides to be ignited and burn toward the center of the remaining pieces of propellant. The intensity of the fire and the density of the column of smoke can be seen in the photograph in Fig. 2.12. This photograph was taken from north of the burn pad and indicates the effect

of the winds on the smoke column and any particles that it might be carrying.

Monitoring of the area surrounding the burn pad immediately after the test revealed no trace of thoria contamination, but traces of thoria were detected on the surfaces of the GIS's that contained unclad thoria simulant fuel spheres.

Some 5 to 10 min after the completion of the burn the center of the 8-pack down between the FSA's could be seen to be still glowing white hot. That condition persisted for some time and probably accounted for a large fraction of the total ablation that was noted on the GIS's after they were removed from the 8-pack. The remains of the HSA mock-up can be seen, about half covered with the remains of the steel plate, in Fig. 2.13. The disk-shaped object to the right and leaning against the HSA is the remains of the end crush-up material that was placed on top of the 8-pack. This disk was probably knocked off when the steel plate fell on the specimen late in the burn. Figure 2.14 is a photograph of the HSA remains, taken from approximately the same position as was Fig. 2.13, after the remains of the steel plate had been removed. In this photograph, one can make out the shapes of the two FSA's in the top layer nearest the camera.

On close inspection, it was noted that both of the panels of the 1r outer clad nearest the burning propellant had been almost completely consumed. Only the thicker ring, on which the lifting lugs are mounted, was left intact on that side of the HSA. The graphite retaining ring of the 8-pack had been almost burned through, but still retained all eight FSA's. The eight GIS's seemed to be ablated more severely than were those in the FSA test, but most of the ablation seemed to be confined to those portions of the GIS's that were nearest the center of the 8-pack. When the HSA and sand of the burn pad had cooled sufficiently, the HSA remains were removed to CMB-5 for further photography and posttest examinations.

The tungsten-rhenium thermocouple with its graphite housing survived the fire with no apparent damage. Unfortunately, the power to the

recorder was lost shortly after ignition, and none of the output from the thermocouple was recorded. A test at that time indicated that the thermocouple was still intact and functioning properly.

3.0 POSTTEST EXAMINATION

3.1 FSA

Both MHT-43 and MHT-55 were subjected to a complete post-mortem by E. M. Cramer of CMB-5 following the fire test. Only the results pertaining to MHT-55, the main test specimen, will be reported here.

In addition to the two FSA's, samples of sand, slag, and a portion of the steel plate were brought in for posttest examinations. The plate had been partially melted and the liquid metal together with slag and sand had been in intimate contact with both FSA's.

MHT-55 was embedded in the sand and slag, which also covered the remains of the steel plate. Figures 3.1 and 3.2 show MHT-55 in the slag and sand as it was received from the test site. This conglomerate of sand and slag was fused into a nearly solid mass containing a considerable amount of iron. However, it was easily detached from the GIS of MHT-55, leaving the GIS substantially intact. The exterior damage was confined to the cavity eroded in the surface by the molten steel shown in Figure 3.3. This cavity matched exactly the protrusion on the steel plate shown in Fig. 3.4, at the site where MHT-55 was resting at the conclusion of the fire test. It is evident from these two photographs that considerable local dissolution of carbon took place, but the GIS was not breached.

Once the steel, slag, and sand were removed, the GIS was easily opened by unscrewing the cap. The interior of the GIS appeared clean and bright, as can be seen in Fig. 3.5. However, combustion products and slag had entered the GIS along the threads and reacted with the Ir PICS. The effects of these reactions can be seen in Fig. 3.6.

The damage to the PICS of MHT-55, made of ORNL WC iridium, was confined to the surface reactions with materials that had penetrated the GIS through its threaded joint and its inherent porosity. The major contaminant of the PICS appeared to be aluminum. The reaction of the iron seemed to be confined to the dissolution of the carbon on the outer surface of the GIS. Photomicrographs, shown in Figs. 3.7 through 3.10, indicated that the interaction of the alumina and slag was confined to the outer surface of the PICS and showed no signs of breaching or seriously weakening the PICS in any way.

3.2 HSA

The mock-up of the damaged FSA was removed from the debris of the solid propellant test and delivered to CMB-5 for photography and post-test examinations. The condition of the specimen as it was received by CMB-5 is indicated in Figs. 3.11 and 3.12. The photograph in Fig. 3.11 is of the side of the HSA that was nearest the burning propellant. The photograph in Fig. 3.12 is of the opposite side, away from the fire. It can be seen in Fig. 3.11 that the 8-pack retaining ring has been separated and is not lending much in the way of containment. It was damaged but not separated at the end of the burn, so the separation must have occurred during transportation from the test site.

The main damage suffered by the HSA was to the two panels of the outer Ir clad nearest the fire. Both of these panels, as can be seen in Fig. 3.11, were almost completely consumed during the test. As is evident in Figs. 3.11 and 3.12, the back two panels remained nearly intact, with the exception of some melting that occurred along their edges. The white material seen in both figures is primarily alumina from the burning propellant. The HSA also contained some sand and several large pieces of steel that entered it in the molten state and solidified after the test. Some of this molten steel had dissolved part of the graphite of the GIS's, but none had come close to eroding through to the PISA's.

The GIS's showed some signs of ablation in addition to the solution by the molten steel, but all were intact when removed from the HSA mock-up. Of the four FSA's with Ir PICS, only the three nearest the fire were examined as part of the posttest analysis. The other, which was used only as a thermometer for the preheat cycle, was away from the fire and was in a less severe environment.

MHT-44, containing an Engelhardt Type III Ir PICS, was in the bottom layer nearest the burning propellant as indicated in Fig. 2.8. This FSA was among the most severely damaged of those used in the HSA for the Phase I impact test. Most of the damage to the GIS seen in Fig. 3.13 was sustained in the Phase I test and not in the solid propellant fire test. Nevertheless, as battered as it was, the GIS could be easily opened by unscrewing the cap. The GIS and PISA are shown in Fig. 3.14. It was evident from the inside of the GIS and the surface of the PICS that only a small amount of impurities entered the GIS through the threaded joint at the cap and reacted with the Ir of the PICS. A close-up of the PICS, Fig. 3.15, shows that this reaction was confined to the outer layer of the surface.

MHT-37, containing an Engelhardt Type II Ir PICS, was in the top layer of FSA's as indicated in Fig. 2.8. This GIS showed some signs of ablation which can be seen in Fig. 3.16, but it also could be easily opened by unscrewing the threaded cap. As with MHT-44, the main damage to the PICS was the small amount of materials entering the GIS through the threaded joint of the cap and depositing on the PICS, as shown in Fig. 3.17. The close-up of this PICS, Fig. 3.18, shows an overall deposition pattern that suggests that the fire products also entered the GIS through its inherent porosity. However, as was the case of MHT-44, these reactions were confined to the outer surface of the Ir and in no way appeared to reduce its ability to contain the fuel sphere.

MHT-57, containing an ORNL Type WC Ir PICS, was in the top layer next to MHT-37, as indicated in Fig. 2.8. As was the case for MHT-44,

the major damage to the GIS occurred in the Phase I test. However, this GIS did show signs of ablation and some effect of the solution by molten steel, as shown in Fig. 3.19. The effects on the PISA, however, were similar to the other two cases described above. Photographs of the GIS and PISA are given in Figs. 3.20 and 3.21.

Since the damage to the PICS in this test was so much less than that to the PICS in the single FSA test, no metallographic sections of these PICS were removed for further analysis. However, sections were taken from the Ir outer clad and are shown, mounted for examination, in Fig. 3.22. Indicated on this photograph are the three areas that were examined carefully and are shown enlarged in Figs. 3.23, 3.24, and 3.25. In all three areas, considerable amounts of Fe, Si, and Al were found alloyed with the Ir. In all the areas examined, no evidence was found to indicate that any of the Ir melted without being alloyed with one of these impurities. However, melting of pure iridium cannot be completely ruled out, even though it was not observed. Future tests involving solid propellant burning temperature and heat flux measurements should help to determine whether or not melting of pure iridium could have taken place in such a fire environment.

4.0 DISCUSSION

The results of the FSA fire test indicate that as long as the GIS is intact, it affords considerable protection for the PISA in a single proximity solid propellant fire environment. For one thing, the GIS seems to provide an effective thermal shield for the iridium PICS. Evidently, the temperature at the surface of a PICS in an FSA is considerably lower than that at the outer surface of the GIS. The temperature of the PICS of an FSA, placed in the fire with the test specimen, was measured during this test, as described above. Although the thermocouple failed before the completion of the test, it did indicate that the maximum temperature of the

PICS of an FSA, introduced to the fire without being preheated, would probably not exceed $\sim 1650^{\circ}\text{C}$ (3000°F). This is in good agreement with the maximum PICS temperature predicted in a calculation by Coin³ of APL. Of course, neither that calculation nor this measurement took into account the effect of the thermal source of a "live" fuel sphere.

Probably of more importance, the GIS seems to be relatively effective in isolating the iridium of the PICS from the impurities of the fire environment, especially the iron from steel that might be in the area. The degree of solution of the graphite of the GIS by molten steel that occurred in this test was not enough to breach the GIS, nor did it have any adverse effects on the iridium of the PICS. However, appreciable amounts of molten steel did not come into intimate contact with the GIS until some time into the test. It is, therefore, not obvious that intimate contact with steel from the beginning of the fire test might not result in the GIS being breached. Such a failure of the GIS would probably result in a significant reaction between the iridium PICS and molten steel, conceivably causing the PICS itself to be breached.

The conditions of the FSA's after the HSA fire test were not surprising, considering the results of the single FSA test. There was slightly more ablation of the GIS's, but most of this probably occurred after the propellant was exhausted, while the center of the HSA 8-pack continued to burn for several minutes. Of course, in a live HSA the burning would continue longer and the ablation would be greater because of the fuel's heat input. The main damage to the HSA was that sustained by the iridium panels of the outer clad. The amount of alloying and subsequent melting that occurred to the two "front" panels suggests that an unprotected PISA might suffer similar damage and be seriously breached as a result of such a solid propellant fire environment. However, since all of the PISA's remained contained within their GIS's during the low velocity impact tests, the effect of the fire

environment on a bare PISA was not considered as a part of this LES 8/9 test.

5.0 CONCLUSIONS

Based on the results of these tests and the posttest analyses, the following conclusions can be reached:

1. The PICS of FSA's contained within a damaged HSA would not be breached nor seriously affected by the environment encountered in a single proximity solid propellant fire of up to eight minute duration.
2. Part of the outer iridium clad of a damaged HSA would be consumed in a single proximity solid propellant fire, but the ability of the HSA to contain the FSA's would not be seriously degraded.
3. An FSA with the GIS intact would survive a nine minute single proximity solid propellant fire without the PICS being breached or seriously damaged.
4. An FSA, either by itself or contained within a damaged HSA, should not be seriously affected by the presence of excess iron (such as that afforded by the steel casing of the SRM) in an environment of a single proximity solid propellant fire, provided that the GIS remains intact.

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2. "Safety Test No. S-3 Solid Propellant Fire," G. E. report GEMS-414 (July 1973).
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Fig. 2.1 The PISA from MHT-55 as it appeared after the Phase I HSA impact test.

Fig. 2.2 Test setup for FSA fire test, showing the preheat oven, wood ramp, and cube of solid propellant. Also shown are the positions of the two FSA's during the test.

Fig. 2.3 The FSA fire test, with smoke column engulfing the drop tower at the LASL K-site facility.

Fig. 2.4 Burn pad after the FSA fire test.

Fig. 2.5 Close-up of burn pad after the FSA fire test, showing remains of the steel plate and relative locations of the FSA's.

Fig. 2.6 PICS temperature of MHT-43 as a function of burn time for the FSA burn test. (MHT-43 was not preheated.)

Fig. 2.7 Photograph from the Phase I HSA impact test, showing the intact 8-pack used in the HSA fire test.

Fig. 2.9 Remains of Ir outer clad and end of aeroshell from the Phase I test used to construct the HSA mock-up.

Fig. 2.8 Diagram of the HSA mock-up as seen from above, indicating the location of the four Ir clad PISA's. The unidentified FSA's contained unclad thorium spheres.

Fig. 2.10 Test setup for HSA fire test, showing preheat furnace and stand, cube of solid propellant, and steel plate.

Fig. 2.11 Close-up of test setup for HSA fire test.

Fig. 2.12 HSA fire test burn and subsequent smoke column.

Fig. 2.13 View of burn pad after HSA fire test showing location of HSA mock-up relative to the remains of the steel plate.

Fig. 2.14 Remains of HSA mock-up on the burn pad after the steel plate was removed.

Fig. 3.1 MHT-55 with slag, sand and remnants of the steel plate attached, as seen from above the pad. Flame front would be to the bottom of the picture.

Fig. 3.2 MHT-55 as viewed from the location of the burning propellant. The sand was below the specimen on the pad.

Fig. 3.3 GIS of MHT-55, showing eroded area that was in contact with the steel plate.

Fig. 3.3 GIS of MHT-55, showing eroded area that was in contact with the steel plate.

Fig. 3.4 Edge of the steel plate where MHT-55 came to rest during the FSA fire test.

Fig. 3.5 Interior of GIS of MHT-55 after the FSA fire test.

Fig. 3.5 Interior of GIS of MHT-55 after the FSA fire test.

Fig. 3.9 Section a of Fig. 3.7. $\approx X150$. Etched.

Fig. 3.10 Section b of Fig. 3.7. $\approx X150$. Etched.

Fig. 3.11 HSA mock-up after solid propellant fire test (point nearest flame front).

Fig. 3.12 HSA mock-up after solid propellant fire test (side away from flame front).

Fig. 3.13 GIS of MHT-44 after fire test.

Fig. 3.16 GIS of MHT-37 after fire test.

Fig. 3.14 Inside of GIS and PISA of MHT-44 after fire test.

Fig. 3.17 Inside of GIS and PISA of MHT-37 after fire test.

Fig. 3.15 PISA of MHT-44 after fire test.

Fig. 3.18 PISA of MHT-37 after fire test.

Fig. 3.19 GIS of MHT-57 after fire test.

Fig. 3.21 PISA of MHT-57 after fire test.

Fig. 3.20 Inside of GIS and PISA of MHT-57 after fire test.

Fig. 3.22 Metallographic sections from iridium clad. a) Away from flame front. b, c) Edge toward flame front (top right of Fig. 3.12). Locations of the following three figures are also indicated.

Fig. 3.23 A section from the top of the clad just back from the edge facing the flame front. $\approx X75$.

Fig. 3.24 A section of the edge of iridium clad facing the flame front. $\approx X75$.

Fig. 3.25 A section from an alloyed area some distance back from the edge facing the flame front. $\approx X75$.