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**Safety Test No. S-6 Launch Pad Abort
Sequential Test
Phase I: Low-Velocity HSA Impact**

by

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MASTER

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

PHASE I: LOW-VELOCITY HSA IMPACT

by

Edward C. Snow

ABSTRACT

Phase I of the MHW Safety Test No. S-6 was conducted at LASL on March 22, 1974. This low-velocity impact test consisted of preheating a simulant MHW-RTG heat source and dropping it from a 45.7-m (150-ft) tower onto a concrete target pad. The heat source impacted at approximately 30 m/sec (100 fps), at an angle of 60° to the horizontal plane.

The nearly inelastic impact resulted in the failure of the outer clad along most of the weld joints and a complete breakup of the aeroshell. The remains did provide containment for all but two of the FSA's, that rolled a few feet away from the point of impact. All 24 FSA's were intact, with the PISA's contained within the GIS's. No thoria release was detected in the target area or on any of the PICS during posttest examinations, even though several of the Ir PICS suffered small cracks

1.0 INTRODUCTION

In preparation for the Air Force Les 8/9 space mission, a series of tests have been and are being performed to evaluate the nuclear safety capability of the Multi-Hundred Watt (MHW) Radioisotope Thermoelectric Generator (RTG) to be used in the mission. One such safety test is Test No. S-6, Launch Pad Abort Sequential Test. The objective of this test was to subject the RTG to the sequential environments characteristic of a catastrophic launch pad accident. 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 have been

subsequently eliminated from this sequence. The purpose of this test is to evaluate the capability of the MHW-RTG to survive such a sequence of environments.

This report describes the procedure and presents the results of Phase I of Test S-6, Low Velocity HSA Impact. In this phase of the test, a MHW Simulant Heat Source Assembly (SHSA) was subjected to an impact of ≈ 30.5 m/sec (≈ 100 fps) on concrete simulating the launch pad. This velocity was chosen because it could be achieved by dropping the SHSA from the 45.7-m (150-ft) test tower at the LASL K-Site facility. It appeared to be a reasonable compromise between the estimated launch abort velocity extremes of 27 m/s (89 fps)

and 43 m/s (140 fps). This type of impact test yields information about the rebound and dispersion characteristics of the SHSA that are not available in other types of impact tests, such as air gun and rocket sled tests. This, of course, makes this type of test desirable, even though the velocity is somewhat below the average of the extremes.

The impact attitude was to be such that the longitudinal axis of the SHSA was at an angle of 60° to the horizontal. This angle was selected, somewhat arbitrarily, to yield maximum crushing and shearing forces at impact, with a minimum loss of energy due to angular momentum imparted to the heat source. A more detailed argument for this choice of impact attitude is given in Appendix A.

The rationale in using the heat source without the converter was that neither a real converter nor a good simulant converter was available at the time of the test. This, of course, leaves unanswered the question of what effects the converter would have on the impact response of the heat source. If one considers the effects that the blast overpressure, fragments, and fireball might have on the converter housing, it is quite possible that the heat source would be free to impact without the converter, or that the converter would be in such a weakened state that it would add no appreciable strength to the heat source on impact. It was decided at the January 29-31, 1974, INSRP meeting to place an emissivity sleeve on the heat source for the impact test.

2.0 TEST DESCRIPTION

2.1 Test Specimen

A full scale heat source, shown in Fig. 2.1, was used in Phase I of Test S-6. The heat source, supplied by Mound Laboratory, contained thorium (76% TD) fuel simulant in the Fuel Sphere Assemblies (FSA's). Of the twenty-four FSA's in the heat source, sixteen had T-111 Post-Impact Containment Shells (PICS) and eight had Ir PICS. The eight Ir PICS were in the eight-pack located at the impacted

Fig. 2.1. MHW-RTG Simulant Heat Source Assembly for S-6.

end of the heat source. Of these eight Ir PICS, three were Type II Ir, two were Type III Ir, and three were WC Ir. The type of Ir, identification number, and relative location of these eight FSA's is shown in Fig. 2.2. The first layer was at the "bottom" of the HSA and impacted first, with the point of first contact with the target to have been between FSA's MHT-56 and MHT-44.

A radiograph, showing the "bottom" eight FSA's, is shown in Fig. 2.3. There was no evidence of cracks or other damage in the PICS or fuel simulant. In the axial radiograph shown in Fig. 2.4, the orientation pin placed in the Graphite Impact Shell (GIS) of MHT-37 is plainly evident. It consisted of two small pieces of Ir placed in the cap of the GIS of MHT-37 at the time of the assembly of the heat source at Mound Laboratory.

The emissivity sleeve to be used for this test, supplied by G. E., had an inside diameter approximately 6.4 mm (1/4 in.) larger than the clad of the SHSA, resulting in a very loose fit between them. No problems were encountered in the test, however, because the sleeve was held in place by the clamps used to support the SHSA during the test.

Layer No. 1

Layer No. 2

Fig. 2. 2. Orientation of bottom eight FSA's in SHSA for S-6.

Fig. 2. 3. Radiograph of bottom eight FSA's in SHSA for S-6.

Fig. 2.4. Axial radiograph of SHSA for S-6, showing orientation pin in GIS of MHT-37.

2.2 Test Setup

The impact of the SHSA for Test S-6 was conducted at the K-Site drop tower facility at LASL, shown in Fig. 2.5. To achieve the impact velocity of 30.5 m/sec (100 fps), the SHSA was dropped from a height of 45.7 m (150 ft) in a guided free-fall to impact on the concrete target pad at the base of the tower, shown in Fig. 2.6. The target pad can be seen in the center of this figure, with the intended impact point marked with a cross. Also shown are the containment barrier, guide cables, and guide carriage arresting mechanism.

To insure that the orientation of the SHSA would be as desired at impact, the orientation guide setup shown in Fig. 2.7 was used. The guide carriage holds the SHSA at the proper attitude until impact and is then kept from smashing into the SHSA by the guide carriage arresting mechanism. It was found, through test drops with a dummy aluminum cylinder, that aerodynamic forces tended to cause the heat source to rotate and pull the carriage out of alignment. This problem was solved by making the support cables rigid by enclosing them in fragile quartz tubing and placing a "wing" on the carriage.

Fig. 2.5. Drop tower facility at the LASL K-Site.

The SHSA was attached to the support cables by two clamps. The top clamp, which can be seen in Fig. 2.8, was a stainless steel band, held away from the Ir outer clad by three graphite pads located under each of the lifting lugs. Also shown in Fig. 2.8 is the emissivity sleeve provided for the test by G. E. Not shown is the lower clamp, which was a stainless steel "c" clamp that attached to the base of the Ir on the side opposite the impact point. This clamp was also separated from the Ir clad by graphite pads. Both clamps were designed to introduce minimum interference with the impact response of the heat source.

The test plan called for the SHSA to be preheated to 900°C (1650°F) just prior to the impact. To achieve this, a clamshell oven, provided by G. E., was mounted at the top of the tower so that the SHSA could be preheated in an inert atmosphere just before it was dropped. This setup prior to closing the furnace and raising the assembly to the top of the tower can be seen in Fig. 2.9. Also shown is the SHSA attached to the guide carriage,

Fig. 2.6. Setup at the base of the tower for S-6.

Fig. 2.7. Setup for the orientation of the SHSA in the S-6 impact test.

which in turn is held at the top by the release mechanism. Both the quartz tubing around the support cables and the "wing" on the guide carriage can be seen in this figure. The guide cables, which are not yet attached, are connected to the steel beam just above the release mechanism and pulled taut when the SHSA and oven are in place at the top of the tower, as shown in Fig. 2.10.

2.3 Test Operation

The S-6 low velocity impact of the SHSA was conducted on the morning of March 22, 1974. The day was mostly sunny with a few scattered clouds, the temperature was about 40°F, and the

Fig. 2.8. Simulant heat source and emissivity sleeve. Upper clamp shown in place for S-6.

winds ranged from calm to gusts of approximately 37 km/hr.

The SHSA and emissivity sleeve were attached to the guide carriage support cables and the guide carriage locked in the release mechanism as shown in Fig. 2.9 above. The support cables and quartz tubing were attached to the clamps to hold the cylinder axis of the SHSA at an angle of 60° to the horizontal plane. The oven was then closed around the SHSA, and the whole assembly hoisted to a height of approximately 45.7 m (150 ft) above the target pad, as shown in Fig. 2.10.

With the SHSA, oven, guide cables, etc., all in place for the drop, an argon atmosphere was established in the oven with a five minute purge. A continuous flow of argon through the oven was maintained while the preheating was conducted according

Fig. 2.9. Heat source attached to guide carriage, ready for furnace to be closed and preheating to begin at the top of the drop tower.

to the time and temperature given in Table I. The preheat proceeded in a normal manner until 10:52:30 when the temperature dropped suddenly. It was felt at the time that the thermocouple in the oven had failed, and that the oven would continue heating and eventually reach a temperature too high for the SHSA support hardware. Therefore, the decision was made to turn off the heaters, open the oven, and proceed with the drop.

The SHSA was released a few seconds after the oven was opened. Shortly after release, a high speed camera was activated and recorded the impact of the HSA on the concrete at approximately 3200 frames per second.

After impact, the area was checked for thoria release and found to be free of contamination. Still pictures of the remains were taken at various

Fig. 2.10. View looking up at closed furnace at top of the tower with heat source inside.

stages of the recovery process. Finally all of the remains were taken to CMB-5 for postimpact photography and analysis.

2.4 Results

Due to the problem encountered with the oven during the preheat operation, the temperatures of the components of the SHSA during the drop test were somewhat in question. Inspection of the oven after the drop revealed that the heater element nearest the thermocouple was broken and was the probable cause of the lower temperature readings.

The other three heater elements continued to operate presenting the possibility that the clad temperature was considerably higher than that indicated by the thermocouple, especially on the portion of the clad away from the broken element.

However, results of a temperature test, described in Appendix B, indicate that the outer clad temperature was approximately 610°C (1130°F) at the time of the drop, and that PICS temperature was approximately 460°C (860°F).

The SHSA was released for a guided free-fall of 47.5 m (150 ft). It impacted on the concrete target pad at a velocity of approximately 30.5 m/sec (100 fps). The series of pictures given in Fig. 2.11, taken from

TABLE I
OVEN TEMPERATURE AS A FUNCTION
OF TIME FOR THE PREHEAT CYCLE PRIOR TO
THE S-6 DROP TEST

Time	Oven Temperature (°C)	Remarks
1002	4	Ambient air.
1007	93	
1012	510	
1017	649	
1022	710	
1027	754	Increased cur- rent to heaters.
1032	760	
1037	788	
1042	816	
1047	877	
1052	882	Sudden temp. drop. Suspect T. C. failure yielding erroneous readings!
1052:30	816	
1058	760	
1058:10	760	
		Heaters off, oven open for drop.

Fig. 2.11. A series of frames from the high-speed
photography of the impact of the SHSA
for S-6.

Fig. 2.11 (Continued)

the high speed photography, indicates that the actual impact angle was approximately 59°. The high speed film also revealed that the impact was nearly inelastic, in that the SHSA experienced very little rebound.

At impact, the emissivity sleeve was ripped apart, leaving only about 1/3 of the sleeve intact. The intact portion of the sleeve can be seen, still in place on the Ir clad, in Figs. 2.12 and 2.13.

The outer Ir clad came apart at all the weld joints. This is evident in Figs. 2.12 and 2.13. It is also evident that the remains of the clad did provide substantial containment for the FSA's, allowing only two of them to roll away from the point of impact.

The graphite aeroshell was broken into many small pieces, adding little if anything to the containment of the FSA's.

As mentioned above, all but two of the FSA's were contained within the remains of the Ir clad and aeroshell. Of these two, one rolled about 0.8 m (2.5 ft) away from the point of impact and

the other rolled about 1.4 m (4.5 ft) away. Neither of the GIS's on these two FSA's showed any appreciable external damage. In fact, all of the GIS's were intact and all of the Post Impact Sphere Assemblies (PISA's) were completely contained. Only the sixteen FSA's in the "bottom" two eight-packs were released from their retainer rings. The "top" eight-pack was still intact.

3.0 POSTTEST EXAMINATION

3.1 SHSA and Emissivity Sleeve

The remains of the SHSA and emissivity sleeve from the S-6 drop test were taken to CMB-5 for photography and examination. Figure 3.1 is a photograph of all but the very small pieces of the emissivity sleeve. It appears that it added very little strength to the heat source during impact.

The remains of the Ir outer clad of the heat source are shown in Fig. 3.2. The point of impact was on the top edge of the can nearest the camera, as it appears in this photograph. This corresponds

Fig. 2.12. Pictures taken immediately after S-6 low velocity SHSA impact, before any cleanup.

Fig. 2.12 (Continued)

Fig. 2.13. Pictures of remains of SHSA after S-6 low velocity impact, with guide cables and carriage removed.

Fig. 2.13 (Continued)

to the near edge of the side panel that was separated from the rest of the clad and appears in the lower left of the photograph. The disk and ring in the lower right and most of the small pieces in the foreground made up the cap on the impacted end of the clad. It is evident in this photograph that most of the clad failure occurred along the weld joints. It should be noted that the "top" end cap of the aeroshell remained intact and can be seen lodged in the remains of the outer clad.

The remains of the aeroshell, except for the end cap that remained in the clad, can be seen in Fig. 3.3. It is evident that little containment of the free FSA's was provided by the aeroshell. It would also appear that a considerable amount of energy was expended in crushing and breaking this aeroshell into so many small pieces.

The remains of the inner components of the heat source, except for the eight Ir FSA's, are shown in Figs. 3.4 and 3.5. It can be seen that the "top" eight-pack received very little damage and that, even though the middle eight-pack was broken apart, there was little damage to the eight FSA's it contained.

Fig. 3.2. Remains of Ir outer clad of the S-6 SHSA.

3.2. FSA's with Ir PICS

The eight FSA's with Ir PICS, located in the "bottom" eight-pack, were photographed, radiographed, and disassembled for a complete examination of the PISA's. Examination of the outer clad, the end crush-up, the radiographs taken before impact, and the FSA's themselves, indicate that the orientation of these eight FSA's at impact was as shown in Fig. 3.6. In this figure, the identification numbers in parentheses are to

Fig. 3.1. Remains of emissivity sleeve used in S-6 drop test.

Fig. 3.3. Remains of graphite aeroshell of the S-6 SHSA.

Fig. 3.4. Remains of inner components of the S-6 SHSA.

indicate spheres that are hidden from view behind those shown in front. In the following sections, the examinations and photographs of each of these eight FSA's will be covered.

3.2.1 MHT-45. FSA MHT-45 contained a Type III Ir PICS and was located in the first layer, opposite the point of impact, (see Fig. 3.6). As shown in Fig. 3.7, the GIS sustained very little damage. This is also the case with the fuel simulant, as indicated in the radiographs given in Fig. 3.8, and the PICS as shown in Fig. 3.9.

Fig. 3.5. Sixteen T-111 FSA's from "top" and "middle" eight-pack of the S-6 SHSA.

This is not a surprising result, if one considers the location of this FSA at the time of impact. This FSA was well padded from the impact target by the end crush-up and had no trailing FSA's smash into it from above.

3.2.2 MHT-44. FSA MHT-44 contained a Type III Ir PICS and was located in the first layer and was the first FSA to impact on the target pad. The damage to the GIS, shown in Fig. 3.10, is substantial, though most of it amounts to fraying and delamination of the outermost graphite fibers. Even so, the PISA was contained and the GIS could be disassembled by unscrewing the cap. The PICS was deformed and the fuel simulant broken, as shown in the radiographs given in Fig. 3.11. The PICS deformation is also shown in Fig. 3.12. It is evident from these photographs that the major deformation to the PICS was caused by the trailing FSA's smashing in from above, after the initial impact. Considerable cracking of the iridium occurred in the areas of the most severe deformation,

Fig. 3.6. Orientation of Ir FSA's at impact in the S-6 SHSA. Spheres with I. D. number in parentheses are "behind" spheres shown.

Fig. 3.7. FSA MHT-45 after S-6 drop test.

as shown in Fig. 3.13. Even though these cracks appear to go all the way through the PICS, no thorium could be detected in the area of cracks, even after an effort was made to shake thorium dust through the larger cracks.

3.2.3 MHT-55. FSA MHT-55 contained a Type WC Ir PICS and was located in the first layer

Fig. 3.8. Radiographs of MHT-45 after S-6 drop test taken at (a) 0° and (b) 90°.

Fig. 3.9. PISA from MHT-45 after S-6 drop test.

at the midpoint of the layer, (see Fig. 3.6). The damage to the GIS, shown in Fig. 3.14, was fairly light. The radiographs, shown in Fig. 3.15, indicate some fuel simulant break-up, but not as severe as that which occurred in MHT-44. The PICS deformation, shown in Fig. 3.16, was substantial, and probably was caused by the impact of the trailing FSA, as was the major damage of MHT-44. No cracks occurred in the areas of deformation of this PICS.

3.2.4 MHT-56. FSA MHT-56 contained a Type WC Ir PICS and was located in the first layer, opposite MHT-55 at the midpoint of the layer, (see

Fig. 3.10. FSA MHT-44 after S-6 drop test.

(a)

(b)

Fig. 3.11. Radiographs of MHT-44 after S-6 drop test taken at (a) 0° and (b) 90°.

Fig. 3.12. (a) Damage of PISA from MHT-44 caused by impact.

Fig. 3.12. (b) Damage caused by impact of trailing FSA's.

Fig. 3.6). The damage to the GIS, shown in Fig. 3.17, is somewhat heavier than that sustained by MHT-55, but still relatively light. The extent of fuel simulant break-up, shown in the radiographs given in Fig. 3.18, was very similar to that of MHT-55. The PICS deformation, shown in Fig. 3.19, was somewhat larger than that of MHT-55. The PICS of MHT-56 was cracked in the area of maximum deformation, as can be seen in Fig. 3.20. It should be noted that this was the only case where a failure in the weld joint of a PICS was encountered.

3.2.5 MHT-57. FSA MHT-57 contained a Type WC 1r PICS and was located in the second layer on the impact side of the heat source, (see Fig. 3.6). The damage to the GIS, shown in Fig. 3.21, was fairly light. The frayed fibers in the impact area make it appear worse than it was. The fuel break-up was also light, as indicated in the radiographs given in Fig. 3.22. The gross deformation of the PICS, shown in Fig. 3.23, was less than that experienced by MHT-55 or MHT-56, but still severe enough to cause cracks, as shown in Fig. 3.24.

3.2.6 MHT-43. FSA MHT-43 contained a Type II Ir PICS and was located in the second layer, away from the impact, (see Fig. 3.6). The damage to the GIS, shown in Fig. 3.25, was very

Fig. 3.13. (a & b) Cracks in the PICS of MHT-44, magnified 3X.

slight. The radiographs, given in Fig. 3.26, indicated little or no fuel break-up had occurred. The PICS deformation, shown in Fig. 3.27, was also light, but some cracks did occur, as shown in Fig. 3.28.

3.2.7 MHT-37. FSA MHT-37 contained a Type II Ir PICS and was located in the second layer away from the impact point, (see Fig. 3.6). The damage to the GIS, shown in Fig. 3.29, was very light, as with MHT-43. The fuel simulant breakup

Fig. 3.14. FSA MHT-55 after S-6 drop test.

was also similar, as indicated by the radiographs given in Fig. 3.30. The PICS deformation and cracking were also very similar to that which occurred in MHT-43, as can be seen in Figs. 3.31 and 3.32.

(a)

(b)

Fig. 3.15. Radiographs of MHT-55 after S-6 drop test, taken at (a) 0° and (b) 90°.

Fig. 3.16. PISA from MHT-55 after S-6 drop test.

3.2.8. MHT-40. FSA MHT-40 contained a Type II Ir PICS and was located in the second layer on the impact side of the heat source, (see Fig. 3.6). The damage to the GIS, shown in Fig. 3.33, was heavier than that sustained by the other FSA's in this layer, but the GIS was still in one piece and could be disassembled by unscrewing the cap. The radiographs, shown in Fig. 3.34, indicate appreciable fuel simulant break-up, but not as severe as that observed in the three lead FSA's in the first layer. The PICS deformation, shown in Fig. 3.35, was very similar to that encountered by MHT-57, with a similar amount of cracking, as shown in Fig. 3.36.

Fig. 3.17. FSA MHT-56 after S-6 drop test.

(a)

(b)

Fig. 3.18. Radiographs of MHT-56 after S-6 drop test, taken at (a) 0° and (b) 90°.

Fig. 3.19 (a) PISA from MHT-56 after S-6 drop test.

Fig. 3.19. (b) Impact from trailing FSA on MHT-56.

4.0 DISCUSSION

The major problem that occurred during the drop test was in the preheat cycle. The results of the temperature test described in Appendix B make it evident that the outer clad and PICS temperatures were well below the 900°C (1650°F) called for in the test plan. They indicate the PICS temperature was between 450 and 550°C and the outer clad temperature was between 600 and 700°C. This, of course, raises some questions about the response of the HSA to the impact, especially in

Fig. 3.20. Cracks in the PICS of MHT-56, magnified 3X.

Fig. 3.21. FSA MHT-57 after S-6 drop test.

(a)

(b)

Fig. 3.22. Radiographs of MHT-57 after S-6 drop test, taken at (a) 0° and (b) 90°.

Fig. 3.23. PISA from MHT-57 after S-6 drop test.

the case of the cracks in the Ir PICS. Subsequent low-velocity impact tests, with a PICS temperature of $\approx 1100^\circ\text{C}$, resulted in no cracks, even though the gross deformation was more severe. This suggests that the cracks were due to the low temperature. Further testing is underway, as part of Phase III of the S-6 test, to confirm this argument.

In spite of the temperature problem, some valuable information was obtained from this drop test. One such piece of information is the probable dispersion characteristics of the heat source at impact. This test showed that the dispersion is minimal and that most of the FSA's will probably stay

Fig. 3.24. Cracks in the PICS of MHT-57, magnified 3X.

Fig. 3.25. FSA MHT-43 after S-6 drop test.

(a)

(b)

Fig. 3.26. Radiographs of MHT-43 after S-6 drop test, taken at (a) 0° and (b) 90° .

Fig. 3.27. PISA from MHT-43 after S-6 drop test.

inside of the remains of the outer clad of an HSA impacted at this velocity. Even those FSA's released from the heat source would not be expected to move very far from the point of impact. This, of course, would minimize the probability of free FSA's coming in contact with a large piece of burning solid propellant.

The test also showed that the impact of a heat source at 30 m/s (100 fps) is nearly inelastic, with virtually no rebound. This would make it nearly impossible for the heat source or any of the FSA's to bounce onto a piece of free solid propellant or

Fig. 3.28. Cracks in the PICS of MHT-43, magnified 3X.

Fig. 3.29. FSA MHT-37 after S-6 drop test.

(a)

(b)

Fig. 3.30. Radiographs of MHT-37 after S-6 drop test, taken at (a) 0° and (b) 90°.

Fig. 3.31. PISA from MHT-37 after S-6 drop test.

into the remains of the aborted motor casing full of burning propellant. This indicates that the most probable type of contact with the burning solid propellant would be of the single proximity type, with an FSA or the HSA remains near the burning face of a piece of propellant laying on or near the launch pad.

It was also discovered, during the posttest examination, that the major cause of deformation to the PICS in an impacting HSA is not the initial impact on the pad, but rather the secondary impacts that occur when one or two FSA's smash into the leading FSA from behind. The low temperature of

Fig. 3.32. Cracks in the PICS of MHT-37, magnified 3X.

Fig. 3.33. FSA MHT-40 after S-6 drop test.

(a)

(b)

Fig. 3.34. Radiographs of MHT-40 after S-6 drop test, taken at (a) 0° and (b) 90°.

Fig. 3.35. PISA from MHT-40 after S-6 drop test.

the PICS probably accounts for the cracks observed in this test, but the severity of the deformations would be enhanced by the proper, higher PICS temperature.

Another interesting outcome of this test was that none of the PISA's was released from its GIS, even though the damage to two of the GIS's was extensive. This indicates that even if there were a breach of one of the PICS at the time of impact, the additional containment afforded by the GIS would eliminate any significant prompt release of fuel fines. Subsequent contact with burning propellant could still

Fig. 3.36. Cracks in the PICS of MHT-40, magnified 3X.

cause a vapor release. However, it was also noted in the test that the more severely damaged FSA's stayed inside of the remains of the outer clad and aeroshell and, therefore, probably would not be directly subjected to the solid propellant fire environment.

5.0 CONCLUSIONS

Based on the results of this test and the posttest analyses, the following conclusions can be reached:

1. A low velocity impact of a free MHW-RTG heat source on a concrete launch pad will probably result in the failure of the outer clad and aeroshell and the subsequent release of one or more FSA's.
2. Under the conditions of a low-velocity impact of the type experienced in Phase I of the S-6 test, the dispersion of free FSA's is expected to be minimal and no rebounding or bouncing of free FSA's or the damaged HSA is expected to occur.
3. All FSA's should remain substantially intact, meaning complete containment of all PISA's in their GIS's following a low velocity impact of this type, resulting in no prompt release of fuel, even if one or more of the PICS were breached.
4. It is expected that the leading FSA's will suffer considerable deformation to their PICS as a result of secondary impacts of FSA's smashing in from behind, and that this deformation will be greater than that of the initial impact of the FSA's on the launch pad.

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APPENDIX A
IMPACT ATTITUDE FOR S-6 DROP TEST

The purpose of this Appendix is to describe how the impact attitude of the SHSA was chosen for the S-6 test. Since in an abort situation, the free HSA would probably be tumbling or spinning at impact, the orientation of the HSA with respect to the plane of the launch pad would be completely arbitrary. We must then select an attitude of impact, based on a combination of probability of occurrence and severity.

First, we define an "end-on" impact as one in which $85^\circ < \phi \leq 90^\circ$, where ϕ , as shown in Fig. A. 1., is defined as the angle between the center line of the cylindrical HSA and the horizontal plane. The probability of such an impact (P_E) is then given by

$$P_E = \frac{90^\circ - 85^\circ}{90^\circ} = 0.0556.$$

Fig. A. 1. Impact attitude for S-6 drop test.

Next, we define a "side-on" impact as one in which $0^\circ \leq \phi < 5^\circ$, where ϕ is the same angle as defined above. The probability of this type of impact (P_S) is then given by

$$P_S = \frac{5^\circ - 0^\circ}{90^\circ} = 0.0556.$$

If all other impact attitudes are defined as "corner-on" impacts, then the probability of such an impact (P_C) is given by

$$P_C = \frac{85^\circ - 5^\circ}{90^\circ} = 0.8889.$$

This, of course, indicates that the most likely impact of an HSA in a launch pad abort situation would be of the "corner-on" type.

In a further consideration of the attitude of the HSA on impact, the "corner-on" impacts are split into two groups. The first, an "end-corner-on" (EC), is defined as an attitude where the center of gravity of the HSA is over the end plate at impact, or $67^\circ 2' < \phi \leq 85^\circ$. This impact attitude has a probability (P_{EC}) given by

$$P_{EC} \cong \frac{85^\circ - 67^\circ}{90^\circ} = 0.200.$$

The second group, "side-corner-on" (SC), is defined as an impact attitude where the center of gravity is over the side of the cylinder at impact, or $5^\circ \leq \phi < 67^\circ 2'$. This type impact has a probability (P_{SC}) given by

$$P_{SC} \cong \frac{67^\circ - 5^\circ}{90^\circ} = 0.6889.$$

These considerations indicate that the most probable impact attitude is of the (SC) type, with $5^\circ < \phi < 67^\circ$, as shown in Fig. A. 1.

For the purpose of a single impact test, the impact attitude should be of the most probable type, yet be weighted toward an attitude that will yield near maximum crushing and shearing forces, with

a minimum of energy loss to angular momentum imparted to the cylinder at impact. A somewhat arbitrary choice of θ that fulfills these criteria is

$\theta = 60^\circ$, which was the attitude used for the S-6 low-velocity SHSA impact test. The results of the test confirm that a minimum of the kinetic energy went into angular momentum of the HSA.

APPENDIX B

TEMPERATURE TEST FOR S-6

I. TEMPERATURE TEST FOR S-6

The purpose of this test was to subject a mock-up of a MHW heat source to a preheat cycle as close as possible to that of the one used in the S-6 drop test and continuously monitor the temperature of the components. The mock-up, as shown in Fig. B.1, was constructed with an eight-pack from S-6 in one end, complete with end crush-up and cap, and nearly solid graphite for the rest of the cylinder. Three simulant PISA's were added

to the solid end to increase the weight of the mock-up to equal that of the heat source used in the S-6 drop. The entire graphite cylinder was clad in stainless steel, 0.762 mm (0.030 in) thick on the ends and 0.254 mm (0.010) thick on the sides. A mock up of the emissivity sleeve was constructed from graphite cloth.

The temperature was continuously monitored at four points on the heat source mock-up, using chromel-alumel thermocouples and a multipoint

Fig. B.1. Mock-up of MHW-RTG heat source to be used in temperature test for S-6.

strip chart recorder. As indicated in Fig. B.1, these thermocouples were placed on an Ir PICS, a T-111 PICS, at the center of a fuel simulant, and on the outer clad. The temperature of the oven was also monitored continuously with a thermocouple that was part of the oven control mechanism.

The test was conducted at the LASL K-Site on Thursday, June 18, 1974, starting at 9:00 AM. The day was mostly clear, with an air temperature of 27°C (80°F) and a light breeze blowing. The heat source mock-up, with emissivity sleeve in place, was suspended in the center of the oven on stainless steel cables. The thermocouple leads were brought through the oven at a point where the two halves came together. After the thermocouples were attached to the recorder and the recorder turned on, all four points were checked for ambient temperature readings.

After the oven was closed and all connections complete, the oven was purged with argon for approximately five minutes. The argon was then continuously supplied to the oven at approximately 40 kPa (6 psi inlet) pressure, throughout the remainder of the test. With the argon purge complete, the oven was preset at 900°C (1652°F) and the heaters turned on. The resulting temperatures as a function of time are given in Table B.1, and shown graphically in Fig. B.2. Very shortly after the heaters were energized, an arcing sound was noted coming from inside the oven. It was later determined that this was caused by one of the heater elements failing. Near the end of the heat-up, another heater element failed, yielding the same noticeable sound. Both of these failures are noted in Table B.1 and on the oven temperature curves given in Fig. B.2.

Approximately 10 minutes after the second heater element failed, the oven was turned off and opened, exposing the mock-up to ambient air. On first contact with the air, part of the cloth emissivity sleeve that was in contact with the outer clad burned away. The rest of the sleeve stayed in one piece and remained on the mock-up, as can be seen

TABLE B.1
DATA FROM TEMPERATURE TEST FOR S-6

Time (min.)	Temperature (°C)			Remarks
	Oven	Outer Clad	Ir PICS	
0	27	27	27	
5	77	37	27	Heater failed!
10	288	84	32	
15	493	149	45	
20	618	225	68	
25	704	295	102	
30	749	370	145	
35	793	427	195	
40	827	475	249	
45	860	519	308	
50	871	572	371	
55	882	607	440	Second heater failed!
60	840	627	507	
65	816	650	566	
70	27	542	595	Oven off & open.
75		456	578	
80		421	545	
85		377	510	
90		352	477	
95		322	449	
100		316	420	
105		294	395	
110		274	369	
115		253	348	
120		235	326	
125		217	308	
130		205	290	
135		190	273	
140		178	256	
145		164	241	
150		145	225	
155		139	211	
160		125	198	
165		119	186	
170		104	174	
175		100	162	
180		95	150	
185		87	141	
190		85	131	
195		80	123	
200		74	116	
205		66	108	

in the photograph shown in Fig. B.3. The mock-up was allowed to cool as shown in Fig. B.2, until a sudden rain shower threatened to compromise the results, at which time the test was terminated.

In comparing the oven temperature to that of the S-6 test, also shown in Fig. B.2, it was evident that the early loss of a heater element

Fig. B. 2. Temperature as a function of time of oven and heat source components from temperature test. Also shown is the temperature curve for the preheat prior to the S-6 drop test.

decreased the rate of heating of the oven by a significant amount in the first few minutes. This of course, would be reflected in the temperature response of both the outer clad and the PICS. Even so, the outer clad reached a temperature of 610°C (1130°F) and the Ir PICS reached a temperature of 460°C (860°F) in a time interval similar to that of the S-6 heat up.

It can be concluded from this test that during S-6 drop test heat-up procedure, the outer clad reached a temperature of at least 610°C (1130°F) and the PICS reached a temperature of at least 460°C (860°F), both of which are significantly below the preferred temperature of 900°C (1652°F). However, it should be noted that both the outer clad and PICS temperatures could have been as much as 50°C

(90°F) higher if all four heaters were operative during the same time interval.

Fig. B. 3. Heat source mock-up and emissivity sleeve mock-up after temperature test.

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