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LARGE RADIOISOTOPE
HEAT SOURCE CAPSULE (LRHSC)
ELEVENTH QUARTERLY PROGRESS REPORT
JANUARY-MARCH 1970

AEC Research and Development Report

Atomics International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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FOREWORD

This is the eleventh quarterly progress report, describing the technical status of the Large Radioisotope Heat Source Capsule (LRHSC) Program. It covers the work accomplished by Atomics International during the period from January 1, 1970 through March 31, 1970 under contract AT(29-2)-2338 for the U.S. Atomic Energy Commission.

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I. INTRODUCTION

The Large Radioisotope Heat Source Capsule (LRHSC) Program was established to develop the technology of an isotope fuel capsule capable of operation in a space environment at a surface temperature of about 2000 °F for five (5) years or more. The program has included the design, fabrication, test and evaluation of a tantalum alloy capsule whose design takes into account the operating requirements of a typical heat source. During the first quarter of GFY 1970, the tantalum alloy capsule technology developed under the LRHSC Program was selected for use in the Transit Program. At that time the LRHSC Program was reconfigured into two (2) series of tasks. The first series of tasks is a continuation of the high temperature isotope fuel capsule technology program. The second series of tasks provide direct support to the development of the isotope fuel capsule for the Transit RTG. Section II of this report contains a description of and a progress report on each of the tasks in the High Temperature Capsule Technology Program. Section III contains the same information for the tasks in the Transit Support Program.

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II. HIGH TEMPERATURE CAPSULE TECHNOLOGY PROGRAM

The objective of this program continues to be the development of the technology for an isotope fuel capsule capable of operation in a space environment at a surface temperature of 2000 °F or more for five (5) years or more. The work includes process, fabrication and test activities. The process and fabrication has included the work required to define an acceptable manufacturing specification for the reference design capsule and to manufacture the test items required for the program. The test program involves various coupons and capsules with evaluation of chemical compatibility, thermal cycling and adherence of coatings, capsule creep, capsule impact and capsule survival in potential abort environments. The data generated in this program will be used to validate design approaches and define design margins that would exist for high temperature capsules intended for flight systems.

The high temperature capsule technology program is being accomplished under the following tasks:

- A1 - Technology Program Management
- A3 - Hardware Design, Fabrication and Assembly
- A4 - Capsule Creep Testing
- A5 - Capsule Impact Testing
- A6 - Material Compatibility Testing

The objectives and progress during the quarter for each of the above tasks follow.

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TASK NO. A1 - TECHNOLOGY PROGRAM MANAGEMENT

Task Objectives

The objectives of this task are to provide management, direction and planning for all aspects of the High Temperature Capsule Technology Program. This includes technical direction, reporting, detailed plans and procedures.

Summary of Status

The technology program milestones are shown in Table A1-1. The program is on schedule with regard to the milestones with the exception that the coupon compatibility testing will be completed in May rather than March.

TABLE A1-1
TECHNOLOGY PROGRAM MILESTONES

	Dates
	→
1. Complete Reference Capsule Impact Test Series	Completed
2. Release Reference Capsule Impact Test Topical (Topical Report No. 8)	Completed
3. Complete Compatibility Testing (out to 1,000 hours and up to 2500 °F)	May 1970
4. Release Preliminary Creep Test Topical (Topical Report No. 10)	June 1970
5. Release Compatibility Test Topical (Topical Report No. 10)	June 1970

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TASK NO. A3 - HARDWARE DESIGN, FABRICATION, AND ASSEMBLY

Task Objectives

This task contains all efforts related to hardware design, fabrication, and assembly in support of other program tasks. The principal effort will be the fabrication and assembly of five (5) capsules for the thermal and impact test tasks. One capsule will be fabricated which contains an internal heater to simulate capsule operation when fueled. All supporting test fixtures for the coupon test task will be built under this task.

Summary of Task Status

Fabrication and assembly of the LRHSC internally heated capsule was completed and the capsule put on test during the second month of the quarter. With the capsule running at 200 watts the heater wire in the feed-through tube burned out. A new heater was fabricated using nicrome wire instead of tantalum wire. The capsule is being reassembled and will be put back on test during the next quarter.

Accomplishments During the Quarter

The LRHSC internally heated capsule was put on test 2-20-70. The power was applied slowly to allow the heater and capsule to stabilize. With the power being increased in 25 watt increments, an input of 200 watts was reached. The heater power was then lost. The capsule was removed from the glove box and partially dismantled. No continuity could be recorded on the heater. The liner was removed to allow for a visual examination of the heater. This examination disclosed that the Ta heater wire had burnt in two approximately half way up the feed-through tube. A new heater is being fabricated using nicrome wire. This capsule will be reassembled and put back on test next month.

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TASK NO. A4 - CAPSULE CREEP TESTING

Task Objectives

The LRHSC Program fuel capsule design utilizes a first generation tantalum alloy (TA-10W) for primary containment of the fuel, a second generation tantalum alloy (T-111) for secondary containment, and Pt-10%Rh for oxidation protection of the reactive refractory metal containers. The objective of this task is to provide and test a design approach that accounts for creep deformation at elevated temperatures for this capsule design.

To achieve this end a test series has been designed to evaluate heat-to-heat variations on the creep of the T-111 structural shell, determine the effects of variable stress on creep of the shell, relate uniaxial and biaxial stress states to creep of T-111 and finally to determine the interacting effects of capsule components on the creep of the structural member.

Creep testing activities during GFY 1970 will be related to completing on-going tests, post test evaluations and documentation of results. No new tests will be initiated during GFY 1970. Post test analysis and documentation will be completed on capsules tested in GFY 1969 and those completed in GFY 1970. A topical report summarizing this work will be released during the year.

Summary of Task Status

Creep testing of Capsules B-3a and B-6a continued during the reporting period. These capsules are long term tests of the T-111 structure shell. Statistical analysis of the data generated by the program was begun during the quarter.

Accomplishments During the Quarter

There are two tests remaining in operation to complete the presently scheduled program. B3a was scheduled to reach 0.1% strain under a constant stress in 2800 hours, thereafter it was to be pressurized at a rate sufficient to induce 1% total strain in the following 6600 hours. The scheduled total test time was to be 8800 hours. The capsule has been under test for a total of 7575 hours, and the apparent strain is 0.753%. The test appears to be right on schedule. The test behavior is shown in Figure A4-1.

Figure A4-1. Creep Capsule B3a Test Behavior

Figure A4-2. Creep Capsule B6a Test Behavior

Capsule B6 was to be stressed at the same rate as B3; however the pressure rate will continue until 5% total strain or rupture is achieved. The test has now logged 7531 hours of time and achieved 0.818 apparent strain. The test is operating satisfactorily. The test behavior is shown in Figure A4-2.

Statistical analysis of the data generated by the program was begun during the quarter. The approach being used is to first develop a strain time relationship for each of the tests. Once this has been developed, the equation is differentiated to yield strain rates for various times during each test. The stress at each time is calculated and related to the strain rate. The best fit for a stress versus strain rate relationship will then be developed for each test. To date, the strain time relationships for all tests have been developed, and the equations differentiated. Three example tests representing long and short term, high and low strain have been selected and are being used to scope stress, strain rate relationships. Once the most promising equation forms are selected from these three, they will be applied to all the tests for correlation.

The analysis should be completed early next quarter for incorporation into a topical report summarizing the creep test program.

TASK NO. A5 - IMPACT TESTING

Task Objectives

The objective of this task is to determine, by testing, the capability of the reference capsule design to survive impact. The developmental impact tests will also allow insight into the actual capsule deformation phenomena, determine the capsule failure modes and ascertain the relative influence of various capsule impact parameters on capsule failure. During GFY 1970 a total of 4 capsules will be impacted on a granite target at various velocities, impact angles, and temperatures. Post-test analysis and documentation will be completed on all GFY 1969 and GFY 1970 capsules and a topical report summarizing this work will be released during the year.

Summary of Task Status

Two (2) LRHS capsules were impacted last quarter. Both capsules were 0.082-inch wall configuration "A" capsules. Impact Capsule A-10 was impacted at 1200 °F and 450 ft/sec. while impact capsule A-11 was impacted at 1200 °F and 400 ft/sec. During this quarter, impact topical (AI-AEC-12922) was published and released. This completes the LRHSC impact test program for this year.

Accomplishments During the Quarter

As reported last quarter, impact capsules A-10 and A-11 were impacted. A-10, Figure A5-1, was impacted end on at 450 ft/sec. The capsule incurred sheer failure encompassing approximately 280 ° of the impact surface. There was no gross loss of the tungsten-moly powder fuel simulant.

Capsule A-11, Figure A5-2, was impacted end on at 400 ft/sec. This capsule also was breeched at the impact end. The crack is similar to the one in Capsule A-10 except it encompasses only 100 ° of the impact surface. Figure A5-3 shows the impact surface of these two capsules.

The LRHSC impact capsule topical (AI-AEC-12922) summarizing the complete impact test program was published and released during the quarter.

Figure A5-1. Impact Capsule A-10

Figure A5-2. Impact Capsule A-11

A-11

A-10

Figure A5-3. Impact Surface Showing
Cracks in A-10 on the right and A-11
on the Left.

TASK NO. A6 - MATERIAL COMPATIBILITY

Task Objectives

The LRHSC design requires that many dissimilar materials including noble metals, refractory metals and various ceramics be placed in close proximity or in contact with one another. The operating conditions for the capsule (2000 °F for 5 years) are in a temperature range where the rates of solid state diffusion and vapor transport may be increased to levels which would cause significant degradation of the mechanical properties of capsule materials. To insure structural integrity of present and future capsules the compatibility task will determine the reactions that occur between the various materials proposed for capsule construction and evaluate what deleterious effect these reactions will produce during the lifetime of a capsule.

During GFY 1970, three (3) types of compatibility tests will be conducted. These are structural and liner materials, emittance coating and holdddown materials, and reentry materials. Testing will be conducted at 2000 °F, 2250 °F, and 2500 °F for times of 10, 100, and 1,000 hours.

Summary of Task Status

As reported last quarter, the materials and holders required for the coupon compatibility tests were received. The compatibility test rig was moved into the new LRHSC test area; and, the first coupon stack CS-24-1 was fabricated, assembled, and tested for 100 hours at 2250 °F.

This quarter coupon stacks CS-21-1 and CS-21-2 were fabricated, assembled, and tested for 100 hours at 2000 °F.

Accomplishments During the Quarter

Identification of the coupon stacks is being maintained according to Table A6-1.

TABLE A6-1
MATERIAL COMPOSITION TEST MATRIX

	10 Hours	100 Hours	1000 Hours
2000°F		CS-21-1 Test Complete 3/9/70 CS-21-2 Test Complete 3/8/70	CS-22-1 Assembled 3/22/70 CS-22-2 Assembled 3/22/70
2250°F	CS-23-1 Assembled 3/22/70 Test Complete 3/27/70 CS-23-3 Assembled 3/22/70 Test Complete 3/23/70	CS-24-1 Complete 1/2/70	Coupons and Holder Available CS-25-1 CS-25-2
2500°F	CS-26-1 Coupons and Holder CS-26-2	Coupons and Holder Available CS-27-1 CS-27-2	Coupons and Holder Available CS-28-1 CS-28-2

Key: CS-2X-Y

CS: Indicates "coupon stack"

CS-2X: The digit two indicates the second series of coupon stacks. The X digit will be from 1 to 8 and corresponds to the test parameters.

CS-2X-Y: The Y digit indicates the type of coupon stack, A-1 type contains only refractory metals, platinum alloys and alumina coating. The -2 type contains emittance coatings, reentry materials as well as refractory metals.

As is shown in Table A6-1, five coupon stacks were tested during the quarter. In addition, two other coupon stacks were assembled for the 1000-hour, 2000°F test.

The refractory metal interfaces of CS-24-1 were examined and photographed. The interfaces were unetched, however, the microstructure of the TZM is visible without etching. The Mo-50Re coupon shows pitting at the grain boundaries which occurred during an attempt to etch the Pt-20Rh coupons.

Investigation of the condition of the noble metal interfaces shows reactions at all interfaces containing Pt-20Rh. Figure A6-1 shows what is equivalent to as received TZM (stress relieved condition). This photograph was taken in the tapered section of the TZM coupon and was not in contact with other coupons at this point although it underwent the same test condition.

Figure A6-2 shows the interface of TZM and Ta-10W. Premature recrystallization of the TZM has occurred at this interface to a depth of approximately 0.015-inch. It is well known that there is a sharp dependence of the recrystallization temperature on the presence of solute in the material. The greater the purity of the metal, the lower the recrystallized temperature. From this fact it seems reasonable to assume that the TZM alloy is being depleted of one or more of its alloying elements by diffusion which brings about a lowering of the recrystallization temperature. The extent of the depletion or the exact elements which are being depleted cannot be determined metallographically. Later in this task the electron beam microprobe will be used to qualitatively determine the nature of the diffusion of this interface.

Figure A6-3 shows the interface of Ta-10W and Nb-1Zr. In this photograph and with examination at higher magnification, there is no apparent reaction at the interface which is observable in the unetched condition of the material.

Figure A6-4 shows the interface of Nb-1Zr and TZM. The portion of the TZM coupon which is not in contact with the Nb-1Zr shows the premature recrystallization noted in the TZM, Ta-10W interface. The concentration gradient of zirconium in the TZM, Nb-1Zr interface is lower than that in the Ta-10W, TZM interface and it is noted that the recrystallization occurs again to a significant depth. From this it would seem that the probable diffusing elements from the TZM are carbon and titanium.

Figure A6-1. As-Received TZM

Figure A6-2. CS -24-1 TZM Top
Ta-10W Bottom

Figure A6-3. CS-24-1 Ta-10W Top
Nb-1Zr Bottom

Figure A6-4. CS-24-1 Nb-1Zr Top
TZM Bottom

Figure A6-5. CS-24-1 TZM Top, T-111 Bottom

Figure A6-5 shows the TZM, T-111 interface. The papered portion of the TZM coupon is unaffected while the section which is in contact with T-111 shows recrystallization of the TZM.

Figure A6-6 shows the interface of T-111 and Mo-50Re. In the unetched condition there is no apparent reaction between the coupons.

Figure A6-7 shows the interface of Mo-50Re and TZM. Recrystallization of the TZM does not appear to have occurred at this interface.

Figure A6-8 is the Pt-20Rh, TZM interface. It should be noted that this interface also shows recrystallization of the TZM near the interface. The extent of the recrystallization in the area of the noble metal is not near as extensive as when TZM is in contact with the tantalum or niobium base alloys.

Pt-20Rh coupons were plasma arc sprayed with coatings of iron titanate and platinized alumina. The coatings are approximately 0.003 inches thick and appear to be very adherant. These coupons will be tested with reentry materials (AXF-5Z and RRG) and structural materials for compatibility.

CS-21.1 and CS-21.2 were assembled. Figures A6-9 and A6-10 show the arrangement of these interfaces. The test will be for 100 hours at 2000 °F.

Coupon stack CS-23-2 (10 hr, 2250 °F) was sectioned and examined. Because of the large differences in hardness and polishing characteristics of the various materials in the stack, considerable difficulty was encountered in the metallographic preparation. All portions of the interface are not in the same plane and therefore portions of the photographs will be out of focus. Generally, the photographs are focused on the reacted zone if one exists. There is erosion of all interfaces in CS-23-2 which is apparent as a groove along the interfaces. It is not known at this time whether or not a reaction product has been lost from this area during preparation.

Figure A6-11 shows the interface of TZM and AXF-5Q type graphite. Close examination shows approximately 0.003-inches where the interface has been removed by preparation. Figure A6-12 is the interface of TZM and platinized alumina. This interface also has an eroded area; however, there does not appear to be any intergranular corrosion or identifiable reaction area or products.

Figure A6-6. T-111 Top, Mo-50Re Bottom

Figure A6-7. Mo-50Re Top, TZM Bottom

Figure A6-8. CS-24-1 Pt-20Rh Top TZM Bottom

Figure A6-9. CS-21-1 100 Hours at 2000 °F

Figure A6-10. CS-21-2 100 Hours at 2000 °F

TZM

AXF5Q

Figure A6-11. TZM and AXF-5Q Type Graphite

TZM

Platinized Alumina

Pt-20Rh

Figure A6-12. Interface of TZM and Platinized Alumina

RPG

Grooved Area ≈ 0.002 -In.
 Platinized alumina,
 Plasma Sprayed

Pt-20Rh

Figure A6-13. RPG to Platinized Alumina Interface

AXF-5Q
 Graphite

Sawteeth

Nb-1Zr

Figure A6-14. Nb-1Zr to AXF-5Q Graphite Interface

Figure A6-13 is the RPG (Reinforced Pyrolitic Graphite) to platinized alumina interface. The platinum is not etched and the RPG shows many areas which appear as holes. This latter effect is due to the characteristic structure and density of the material (density 1.8 g/cm^3). There is no apparent reaction at the interface.

Figure A6-14 is the Nb-1Zr to AXF-5Q type graphite interface. Some type of a reaction is taking place that cause the serrated or saw tooth effect shown in the photomicrograph. Etching the sample may reveal more information about the nature of the reaction.

Figure A6-15 is the TZM to RPG (Reinforced Pyrolitic Graphite) interface. The apparent roughness of the TZM interface was caused by some type of reaction with the RPG since the surface was originally uniform. The effect, however, is limited to approximately 0.002-inches and there is no indication of any degradation of the TZM that is not immediately adjacent to the interface. Hardness measurements will be taken to see if any hardness variations are occurring due to the RPG.

Figure A6-16 shows the interface of unetched T-111 and AXF-5Q graphite. A saw-tooth effect can be seen which is due to a reaction with the AXF-5Q. The depth of the reaction is approximately 0.003-inches and there are no apparent indications of long range degradation of the T-111.

Figure A6-17 shows the interface of unetched T-111 and RPG. There is no apparent reaction at this interface.

Figure A6-18 shows the interface of platinized alumina and AXF-5Q graphite. A 0.002-inch groove appears at the interface but there is no apparent reaction.

Figure A6-19 shows the interface of platinized alumina and Nb-1Zr. There is no apparent reaction at the interface.

Other coupon stacks are being examined and photomicrographs taken. Areas which have measurable reacted areas will be measured for establishing rate equations for the reactions. In all the interfaces shown there is no catastrophic reaction such as that previously observed between T-111 and iron titanate.

TZM

RPG

Figure A6-15. TZM to RPG Interface

AXF-5Q

Unetched T-111

Figure A6-16. Unetched T-111 and AXF-5Q
graphite interface

Figure A6-17. Unetched T-111 and RPG Interface

Unetched Pt-20Rh

Plasma sprayed
Platinized Alumina
Grooved Area

AXF-5Q

Figure A6-18. Platinized Alumina and AXF-5Q
Graphite Interface

Unetched Pt-20Rh

Plasma Sprayed
Platinized Alumina

Unetched Nb-1Zr

Figure A6-19. Platinized Alumina and Nb-1Zr
Interface

III. TRANSIT CAPSULE SUPPORT PROGRAM

The tasks being accomplished in direct support of the Transit Capsule Development Program are as follows:

- B1 - Transit Support Program Management
- B2 - Transit Capsule Process Development and Qualification - Completed
- B3 - Transit Capsule Impact Tests
- B4 - Transit Capsule Fire Tests
- B5 - Transit Capsule Explosive Overpressure Tests
- B6 - Transit Capsule Oxidation Resistance
- B7 - Transit Capsule Thermal Verification
- B8 - Transit Capsule Fragmentation Tests
- B9 - Transit-sized Capsule Fabrication and Testing
(Previously designated as Task 8)
- B10 - Fabrication of Transit Capsule Piece Parts

Task objectives, schedules and progress are detailed on the following pages.

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TASK NO. B1 - TRANSIT CAPSULE PROGRAM MANAGEMENT

Task Objectives

The objectives of this task are to provide management, direction and planning for all aspects of the Transit capsule support effort. This includes technical direction, reporting, detailed plans and procedures. Particular emphasis will be directed to maintaining a close liaison with TRW and MRC.

Summary of Status

The milestones for the Transit Support Program are shown in Table B1-1. The program is on schedule with regard to all milestones.

TABLE B1-1

TRANSIT SUPPORT MILESTONES	
	Dates
1. Complete Transit Sized Capsule Impact Tests	Completed
2. Complete Thermal Verification Testing	Completed
3. Complete Transit Capsule Impact Test Program	May 1970
4. Complete Transit Capsule Fire Test Program	May 1970
5. Complete Transit Capsule Overpressure Test Program	May 1970
6. Complete Transit Capsule Fragmentation Test Program	May 1970
7. Complete Transit Post-Impact Oxidation Testing	June 1970

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TASK NO. B3 - TRANSIT CAPSULE IMPACT TESTS

Task Objectives

This task will provide the impact test data and complete post-test evaluation of twelve (12) full-scale Transit capsules. Test parameters will vary angle, velocity, temperature, and fuel simulant, and will be specified by TRW.

Summary of Task Status

Test parameters for the twelve (12) impact capsules were provided by TRW.

A test plan was prepared and approved by Atomics International and TRW program management.

Accomplishments During the Quarter

During this reporting period a test plan was prepared. It establishes the requirements for demonstrating the ability of the Transit Heat Source Capsule to contain the SSC fuel form upon reentry impact.

Twelve full-scale heat source capsules will be impacted at Sandia Corporation's Rocket Sled Facility. The capsules will be supported above the sled track at the angle designated, preheated in an argon atmosphere to the required impact temperature, and impacted with a granite block at a velocity of 326 ft/sec.

The angle of impact will be varied as will the temperature. The two most critical angles of impact and the most critical temperature will be determined as a result of these tests. The test matrix is shown in Table B3-1.

The sheathed chromel-alumel thermocouples for these tests have been purchased and delivered to MRC. Several additional thermocouples were delivered to the AI Thermocouple Standards Laboratory for calibration and verification of the T/C's ability to endure 2400 °F environment for various lengths of time.

TABLE B3-1 IMPACT TEST MATRIX

	Test No.	Impact Angle ⁽¹⁾ (Degrees)	Velocity ⁽²⁾ (ft/sec)	Temperature (°F)
Group 1	TID-1 ⁽⁵⁾	45	326	TBD
	TI-1	0	326	2400 ⁽³⁾
	TI-2	22.5	326	2400
	TI-3	45	326	2400
	TI-4	67.5	326	2400
	TI-5	90	326	2400
Group 2	TI-6	0	326	2000 ⁽⁴⁾
	TI-7	45	326	2000
	TI-8	90	326	2000
Group 3	TID-2 (if req'd	TBD	326	TBD
	TI-9	TBD	326	TBD
	TI-10	TBD	326	TBD
	TI-11	TBD	326	TBD
	TI-12	TBD	326	TBD

(1) Angle between surface of granite block and axis of the heat source.

(2) 110% of the peak measured sea-level impact velocity.

(3) Maximum ground impact temperature predicted by reentry thermal analyses.

(4) Minimum ground impact temperature predicted by reentry thermal analyses.

(5) TID-1 and TID-2 are dummy impact capsules.

NOTE: The test numbers do not indicate the order in which the tests must be performed. The initial tests will be TI-1 and TI-6.

TASK NO. B4 - TRANSIT CAPSULE FIRE TESTS

Task Objectives

This task will determine the response of the capsule to a solid propellant fire simulating a potential launch pad abort condition. Two (2) capsules will be exposed to the fire resulting from a burning block of propellant. Capsules will be instrumented to obtain the transient temperature response. The test configuration may be with or without reentry shield, or with or without oxidation clad, depending on results of overpressure and fragmentation tests. A comparison of fuel retention as well as complete post-test chemical and metallurgical examinations will be conducted.

Summary of Task Status

Test requirements for the two (2) fire test capsules were provided by TRW.

A test plan was prepared and approved by AI and TRW program management.

Accomplishments During the Quarter

Test requirements for the fire test capsules were received from TRW on January 19, 1970. The detailed test plan was prepared and approved.

At a meeting held at TRW on March 19 to review the test plans for all of the design verification tests, no significant changes were made to the Transit capsule fire test plan. The test procedures for this test are presently being prepared for review at Sandia Corporation early next month.

The test configurations are shown in Figure B4-1.

Figure B4-1. Fire Test Configurations

TASK NO. B5 - TRANSIT CAPSULE EXPLOSIVE OVERPRESSURE TEST

Task Objectives

This task will evaluate the capability of the heat source to withstand the shock wave which may result from a launch pad abort. Two (2) capsules will be used for this test, one of which may subsequently be used for sequential testing in Tasks B4 and B8.

Summary of Task Status

Test requirements were provided by TRW. A test plan was prepared and approved by AI and TRW program management.

Accomplishments During the Quarter

Two heat source capsules will be subjected to an explosive overpressure corresponding to an exploding fourth-stage of the Scout Vehicle. They will be of the Transit type with simulated SSC fuel. Both capsules will be mounted on a test tower and simultaneously tested using TNT as the explosive charge. The overpressures will correspond to an air blast from a 40% and 4% yield on the two capsules or to a ground blast from a 20% and 2% yield. The test temperature is 625 °F.

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TASK NO. B6 - TRANSIT CAPSULE POST-IMPACT OXIDATION RESISTANCE

Task Objectives

This task will provide data with regard to the oxidation parameters of actual capsules. It will make use of two (2) impacted capsules from Task B3 and may include verification coupon testing as well as exposure of an internally heated capsule. Tests will vary the temperature and exposure due to cladding breech. Full or partial burial may be examined.

Summary of Task Status

Test requirements for the Transit capsule were provided by TRW. The test plan for this test has been prepared.

Accomplishments During the Quarter

The test plan for this test has been prepared. For present planning purposes, the Trent furnace at the AI Hot Lab will be used to run the oxidation tests.

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TASK NO. B7 - TRANSIT CAPSULE THERMAL VERIFICATION

Task Objectives

This task will provide the data necessary to verify and upgrade the thermal models which are being used to predict steady-state operating, reentry, and post-impact temperatures. A heat source will be assembled using an internal electrical heater and temperature instrumentation at each stage of assembly. The stabilized shell temperature as well as the temperature drops across the various gaps shall be determined. The piece-parts are to be GFE to this task.

Summary of Task Status

Test parameters were received from TRW during the month of November. A test plan was prepared and approved by AI and TRW program management. The test was performed during the quarter and the capsule delivered to TRW. A test report is presently being prepared.

Accomplishments During the Quarter

The development test procedure for the Transit Thermal Verification Test, DTP-734-25-001, was prepared and released. Figures B7-1 and B7-2 show the piece part and capsule assembly configuration with slight modifications from what was reported during the last quarter.

Testing of the tantalum wound alumina heater was completed. The heater was placed in one atmosphere of high purity helium and subjected to 850 watts of power. Three thermocouples were recording temperatures throughout the test. The thermocouple in the center of the heat zone reached a stabilized temperature of 1360 °F.

During the assembly of the heater into the liner assembly, the heater wire broke. Approximately 6-inches on either end of the heater coil was very brittle. The possible causes were a dirty glove box, dirty helium, dirty alumina heater parts, or a combination of all three. A sample heater was run in both a vacuum and a helium atmosphere. After each test the heater was examined and found to be clean and ductile. Therefore, the probable cause of the previous failure was contaminated alumina heater parts. The

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LINER CAP
TRW DRG C405300 ISSUE A
MODIFIED AS SHOWN

LINER BODY
TRW DRG C40549B ISSUE B
MODIFIED AS SHOWN

JUNCTION BOX
304 SST

STRENGTH MEMBER CAP
TRW DRG C40549G ISSUE A
MODIFIED AS SHOWN

STRENGTH MEMBER BODY
TRW DRG C40549S ISSUE B
MODIFIED AS SHOWN

TUBE
PL-10 RH

CLAD CAP
TRW DRG C40549Z ISSUE A
MODIFIED AS SHOWN

CLAD BODY
TRW DRG C40549Z ISSUE B
MODIFIED AS SHOWN

SLEEVE
PL-10 RH

SLEEVE
304 SST

TUBE
Ta-10 W

Figure B7-1. Thermal Verification Capsule
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Figure B7-2. Thermal Verification Capsule
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The alumina was outgassed and packaged in a high-purity argon atmosphere. A new heater was fabricated and tested for approximately one hour at 400 °F in one atmosphere of 99.9999% pure helium (Figure B7-3). To preclude the possibility of glove box contamination, the glove box was thoroughly baked out prior to testing the heater. The heater was then installed into the liner body and the feed-thru assembly and liner body were E. B. welded (Figures B7-4 through B7-6). All of the welds and braze joints were inspected and proved to be leak tight up to the point of assembling the feed-thru flange. The feed-thru flange was then installed and leak checked (Figure B7-7 and B7-8). Several leaks were detected in the high temperature potting compound used to seal the flange.

A second heater was fabricated, and tested, using 0.040 diameter nichrome wire instead of tantalum wire. This was held as a back-up in case the tantalum heater failed.

A new feed-thru flange was fabricated and inspected for leak tightness (Figure B7-9). The liner, configuration II per test plan TP-734-25-002, was assembled (Figures B7-10, 11, 12). All joints were sealed except the joint between the feed-thru flange and junction box. The assembly was placed in the glove box and pumped down to a radius of 2×10^{-4} torr. Power was applied to bring the liner to 200 °F. This was done to bake off any moisture that may have collected during the assembly operations. This temperature was maintained for one (1) hour. The glove box was then back-filled with ultra pure helium to 14.7 psi three (3) times. The feed-thru flange was then sealed retaining one (1) atmosphere of helium inside the liner assembly. The assembly was then leak checked with leak being detected at the three (3) thermocouple exits in the feed-thru flange. The lava sealant proved to be porous to helium. The lava seals were replaced with teflon seals. The evacuating and backfilling procedure was duplicated. The assembly was again leak checked and passed AI Spec. NA0115-012 Rate II.

The assembly was then instrumented with seven (7) external thermocouples. Three (3) T/C's were placed on the liner body to match the three (3) internal T/C's, three (3) were placed on the feed-thru tube to check heat losses through the tube and one (1) T/C was attached to a conax fitting on the

Figure B7-3. Assembled Heater Less Instrumentation

Figure B7-4. Liner Body with
Thermocouples Attached

Figure B7-5. Liner Body, Feed-Through
Sub-Assembly, and Heater
Ready for Assembly

Figure B7-6. Assembled and Welded Liner

Figure B7-7. Junction Box, Feed-Through Tube and Feed-Through Flange Assembled

Figure B7-8. Modified Varian Feed-Through Flange Showing Heater Terminals and Thermocouples Feed-Throughs

Figure B7-9. Feed-Through Flange
Showing Power Feed-Throughs and Conax Fittings

Figure B7-10. Liner Body with Internal T/C's,
Heater Assembly, and Feed-Through Sub-Assembly

Figure B7-11. Liner Assembly Welded

Figure B7-12. Liner Assembly Instrumented
and in the Glove Box Ready for Test

Figure B7-13. Liner Assembly
in a Vacuum at 1925 °F

Figure B7-14. Stitch Weld of
Strength Member Parts

Figure B7-15. Strength Member
with T/C's Attached

feed-thru flange to record the temperature of the teflon seal. While the glove box was pumping down, an attempt was made to index on the capsule diameter with a cathometer. Due to vibration of the glove box, a meaningful measurement could not be taken.

With a vacuum of 7.5×10^{-5} torr, power was applied to the heater until the first reference input of 600 watts was reached. The power was then increased as per the test plan to 700, 807, and 850 watts and the temperature allowed to stabilize at each reference point. With 850 watts input, the maximum temperature recorded was 1925 °F on the liner body. (Figure B7-13) At this point the temperature in the area of the teflon seal was 200 °F.

The vacuum run was completed and the glove box was back-filled with helium to one (1) atmosphere. Again power was applied to the heater using the same parameter as on the vacuum test. At 850 watts input, the maximum recorded temperature was 1470 °F.

The strength member body was then assembled and EB stitch welded to the strength member cap (Configuration III, Figure B7-14). Thermocouples were attached to the strength member body and the capsule placed in the glove box for testing (Figure B7-15).

The first test was in a vacuum. For this test and subsequent tests the power input was limited by a limit of 1900 °F on the liner body. Power was increased from an initial input of 100 watts to 383 watts. At this input the strength member temperature stabilized at 1405 °F and the liner temperature stabilized at 1915 °F. Power was turned off and the vacuum portion of configuration III test was terminated.

After the capsule had cooled down from the vacuum test, the glove box was back-filled with helium to one (1) atmosphere. Power was applied slowly to bring the capsule to stabilized temperatures at reference wattage inputs of 600, 700, 807, and 850 watts input, the liner temperature was 1435 °F and the strength member was 1310 °F.

There was some question as to the validity of the temperatures due to the capsule resting on a block of "glass-rock" which might restrict the heat dissipation. Both the vacuum and helium test for Configuration III were rerun

Figure B7-16. Configuration IV with Three (3) Strength Member T/C's Protruding the Clad and Coating Removed in Six (6) Places for Attachment of Additional T/C's

Figure B7-17. Configuration IV in Glove Box with all T/C's Attached

with the capsule suspended by a 0.060 diameter tantalum wire. The vacuum test was run with a power input of 300 watts and the liner reached 1765 °F with the strength member reading 1250 °F. The suspended capsule was then run in helium. At the maximum required power of 850 watts the liner recorded 1410 °F and the strength member 1290 °F. By suspending the capsule, the recorded temperature was lowered approximately 25 °F.

With the test of Configuration III complete, the clad body, cap and feed-thru tubes were assembled and welded. This assembly was tested as Configuration IV. Six (6) thermocouples were attached to the clad body and the capsule placed in the glove box. During this test twelve thermocouples were recording capsule temperatures. (Figure B7-16 and B7-17).

The first test of Configuration IV was the vacuum test. At 390 watts input and the temperature stabilized, the liner recorded 1845 °F, the strength member 1275 °F, and the clad 1040 °F. The glove box was then back-filled with helium to one (1) atmosphere and the power applied to the capsule in 200 watt increments until the first reference power input of 600 watts was reached and the temperature stabilized. Again the power was increased to 700, 807, and 850 watts. The temperature at 850 watts input of the liner was 1195 °F, the strength member 1065 °F, and the clad 975 °F.

The final test was run to find the helium pressure required to produce a significant drop in the temperature differential between components. The test was started with the capsule in a vacuum. Power was applied slowly until 400 watts was reached and the capsule temperature stabilized at 1885 °F on the liner, 1320 °F on the strength member and 1060 °F on the clad. Helium was bled into the glove box in stages, allowing the capsule temperature to stabilize at each reading. Although all the data has not been evaluated, it appears a helium pressure of 15 to 50 millimeters is required to markedly reduce gap ΔT 's.

With all the tests on the Transit thermal verification capsule complete, the capsule was delivered to TRW.

A test report is in work summarizing the task.

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TASK NO. B8 - TRANSIT CAPSULE FRAGMENTATION TESTS

Task Objectives

This task will test and evaluate the damage to the heat source resulting from fragments or shrapnel produced by a launch pad abort. The test will be performed under controlled conditions by using a sled facility and impacting the heat source into fragments representative of the shrapnel produced in an abort mold.

Summary of Task Status

Test requirements were provided by TRW. A test plan was prepared and approved by AI and TRW program management.

Accomplishments During the Quarter

During this reporting period a test plan was prepared which establishes the requirements for demonstrating the ability of the Transit Heat Source Capsule to withstand the impact of high velocity fragments which may result from propellant explosions during a launch pad abort. Three full-scale heat source capsules will undergo fragmentation damage tests at the Sandia Corporation Rocket Sled Facility.

The heat source will be mounted stationary beside the rocket sled track and the fragment will be supported on the sled in such a manner as to eliminate the possibility of the supports impacting the heat source. The capsule will be preheated to its predicted launch temperature of 1200 °F prior to being impacted with the fragments.

The first two capsules will be impacted at the maximum predicted velocity for the specified type of fragment. The third capsule, being used in a sequential series of abort tests including overpressure, fragmentation and fire, will be subjected to a more realistic fragment impact velocity to prevent it from being tested to a series of worse case and highly improbable conditions.

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TASK NO. B9 - TRANSIT-SIZED CAPSULE FABRICATION AND TESTING

Task Objectives

This task was previously designated Task 8. The objectives of this task are to provide limited process development, examination, fabrication and testing of a Transit-sized, vented capsule. The capsule will have a 0.020-inch Ta-10W liner, a 0.090-inch T-111 structural member, and a Pt-10Rh oxidation clad.

Fabrication process development will be done on ten (10) sets of blanks with the objective of obtaining at least enough piece parts to assemble four (4) vented capsules. Extra piece-parts will be shipped to MRC. A preliminary manufacturing specification will be prepared.

The four (4) assembled capsules will be impact tested by Sandia.

Summary of Task Status

The post test examination on the Task 8 Transit Impact Capsules was completed during the quarter.

Accomplishments During the Quarter

The post test examination of the Transit Impact Capsules was completed during this reporting period. The results of this examination are summarized below.

1. Chemical Analysis

The fuel liners of the first three capsules were grossly embrittled, apparently with residue entrapped in the fuel simulant during processing. High temperature outgassing of the fuel simulant prior to capsule loading has helped to alleviate this problem, particularly with the microsphere unit. The chemical analyses of each capsule is presented in Table B9-1. A comparison of the oxygen content in AIT8-2 with that of AIT8-3 indicates the source of oxygen to be internal (compare liner to T-111). Apparently the contaminants within the fuel discs were released when the capsule was heated to the impact temperature, were contained, but reacted with the liner material causing it to become embrittled.

TABLE B9-1
CHEMICAL ANALYSIS OF AIT8 IMPACT CAPSULES

	T-111				LINER			
	O	H	N	C	O	H	N	C
AIT8-2-1	275	65	38	37	1600	45	74	41
-2	650	70	26	9	3500	180	19	7
-3	625	85	42	34	1080	25	27	36
AIT8-3-1	60	70	29	13	4900	70	48	75
-2	1000	100	49	18	11,000	80	27	37
-3	70	75	46	16	3200	75	116	82
AIT8-4-1	135	35	25		700	5	15	
-2	175	20	95		770	40	30	
-3	60	15	70		310	10	5	
AIT8-5-1	185	15	75		110	10	3	
-2	145	35	10		90	5	2	
-3	170	15	10		80	2	3	

-1 Impact End

-2 Center

-3 End Opposite the Impact End

AIT8-4 and AIT8-5 were subjected to a high temperature outgassing process. The process appears to be sufficient to eliminate the contaminants from the microsphere capsule (AIT8-5) but due to the uncertainty in the temperature data from the arc jet test, it is not known at this time if the high oxygen in the liner is due to improper outgassing of the fuel pucks or excessive overtemperature conditions, measured by real time above 2500°F, when the heat shield ablated through.

The Pt-20Rh cladding cracked on the last two capsules and is the apparent cause of the slight increase in oxygen in the T-111. It is apparent, however, that even though the cladding was cracked in these two cases, it would have provided long-term protection to the T-111 and subsequent fuel containment.

2. Metallographic Analysis

The metallographic examination of the T-111 from AIT8-2 and -3 revealed an average side wall grain size of ASTM 6, and in the ends ASTM 3 with ASTM 8 (Duplex). This is typical of the as-fabricated material. The average grain size of the T-111 in the area near the crack in AIT8-3 was ASTM 5. The hardness of the T-111, however, is 30% higher than normal at the inside wall and 15% higher at the outside wall. The average hardness, excluding the outer and inner 15-mils of wall, is approximately 20% higher than normal in this material. Hardness of AIT8-4 was only slightly above normal and that of AIT8-5 was normal. All hardness numbers were taken from the side wall opposite the impact surface.

The metallography on all of the SSC capsules revealed a problem which is not evident in the microsphere capsule and that is, thinning of the wall in the impact zone. Figure B9-1 is a photomacrograph of AIT8-2 showing a longitudinal cross-section of the impact surface and the thinned region. An overall view for reference to the location of the macro is shown in the inset and the area encircled indicates the region shown in the photomontage of Figure B9-2. One of the factors involved in causing this reduction in wall thickness is the compaction of the SSC fuel in this region at impact and the subsequent impinging forces between the capsule and the granite block.

Figure B9-1. Photomicrograph of AIT8-2 Showing the Thinned Area in the Impact Surface. The sample shown was cut from the area indicated in the inset.

Figure B9-2. The Microstructure of the
T-111 at a Thinned Region
in the Impact Zone
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Apparently in the test of AIT8-4, the interaction of the fuel discs compacting at impact and/or the heat shield breaking apart leaving an uneven or irregular layer of graphite between the capsule and the granite block, was sufficient to cause thinning in the capsule wall and the puncture shown in Figure B9-3. The sample for this macrophotograph was taken from the area shown in the inset. It was cut on a line perpendicular to the crack as indicated on the inset. The area encircled is shown in Figure B9-4. In comparing this figure with Figure B9-2, it is apparent that the deformation characteristics are relatively the same. The material to the right is comparatively non-deformed while that to the left has been highly deformed. The fuel pucks apparently act as blunt wedges, being driven into the containment material as illustrated by the longitudinal cross-section taken from AIT8-3 and shown in Figure B9-5.

It has been demonstrated, within the parameters of these tests, that the tantalum alloy capsule has the ability to contain the solid solution cermet fuel form, without releasing the fuel to the atmosphere, even when the strength member is cracked on impact.

A new series of impact tests for this capsule is planned for this Spring. They will vary the impact angle and temperature to determine the critical parameters. The tests will be reported under Task B-3.

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Figure B9-3. 3X Photomacrograph of AIT8-4

Figure B9-4. Microstructure of the
Capsule Materials at the
Crack in AIT8-4

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Figure B9-5. Longitudinal Cross Section of
AIT8-3 Shows Impression Left by
Edge of Fuel Discs. 3X

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TASK NO. B10 - FABRICATION OF TRANSIT CAPSULE PIECE PARTS

Task Objectives

The objective of this task is to fabricate deep drawn tantalum alloy and Pt-20Rh clad piece parts in accordance with TRW Systems and Isotopes, Inc. drawings. The capsule piece parts are to be used in the development testing of the Transit and Pioneer programs.

Summary of Task Status

Problems were encountered at Mound Laboratory in assembling the initial shipment of piece parts. The problems resulted from inadequate clearances between the subassemblies. Process redevelopment and rework of existing piece parts was accomplished. Deliveries have been completed on the Pioneer piece parts with the shipment on March 30. Twenty-two piece part sets were fabricated for this program. At this time approximately half of the Transit piece part sets have been fabricated and delivered.

Accomplishments During the Quarter

Problems in the assembly of the capsule were encountered at Mound Laboratory following the receipt of the initial shipment of Transit piece parts. All piece parts exhibited a bulging hemispherical radius. This prevented the assembly of the strength member and liner assemblies. In the case of the clad and strength member assemblies, the clearance tolerances at the tangent points prevented assembly. Because of the similarity of the hemispherical radii problem, a common factor between machined parts and coined parts was suspected. This proved to be the case. The tracer lathe template and stylus configuration was incorrect and produced the hemispherical bulges noted. This same lathe/tracer system was used to produce the punches and coining dies for the drawing and coining operations. The lathe tracer stylus was corrected and the coining dies were remade. The double cusp noted in the internal spherical radii of the strength member body was determined to have been caused by improper seating of the punch in the body during the drawing process. The process includes a coining operation following the deep drawing and it was at this point that the punch failed to seat, producing the cusp. The effect of this cusp was to restrict axial motion leaving a clearance of 0.050 to 0.060-inches between the strength member body and the liner assembly.

All piece parts that had been shipped to MRC were returned to AI. Process procedures were demonstrated as follows:

1. Liner Body Rework - Remachine the hemispherical ends to the correct radius.
2. Liner Cap Rework - Remachine hemispherical surface to the correct radius.
3. Strength Member Body Rework - Remachine O. D. spherical radius, internal spherical radius and straighten.
4. Strength Member Cap New Process - Change from a coining operation to a deep draw operation. In addition, introduce intermediate coining steps to form the hemispherical end and final machine the outside spherical radius. Finish machine weld preps and vent holes to drawing requirements.
5. Platinum Clad Body Rework - Final iron with a new die to the 0.018-inch wall thickness. Recoin hemispherical end in a rubber die and machine outside spherical radius to 0.018-inch wall thickness at the correct spherical radius. Remachine new weld prep.
6. Platinum Clad Cap Rework - Recoin in clad body die to eliminate dimple. Machine outside spherical radius and remachine new weld prep.

One of the principal concerns of the piece part assemblies was the availability of clearances for differential weld shrinkage between the sub-assemblies and differential thermal growth that occurs during operational cycles. Fuel envelope gages were constructed at AI for use in determining fuel liner body clearances on the liner body piece parts. Plug gages, "go-no go," were constructed by MRC for use by AI in determining the inside dimensions of the strength member liner and clad sub-assemblies. Adjustable assembly clearance gages were constructed by AI for determining quantitatively the clearances of the sub-assemblies. One of the gages was delivered to MRC for their use in selecting capsule assemblies.

The piece parts have exhibited a continuing upgrading in quality in terms of reduced frequency of deviations and the number of serious deviations.

Piece part weight variations were determined for a sample of 20 piece part sets. Maximum to minimum variation (worst case) was determined to be only 0.151 pounds.

Table B10-1 summarizes the production program status. This status indicates the shipping dates for both Pioneer and Transit. The Pioneer deliveries are complete and the Transit deliveries about half complete. The comparison with the preliminary schedule proposed on February 26, (Table B10-1) has been essentially met.

TABLE B10-1

PIECE PART FABRICATION STATUS

			TRANSIT / PIONEER ACTUAL PIECE PART DELIVERIES														PLANNED DELIVERIES		
PART NAME	PROGRAM	PARTS AT MRE	FEB-26 DEL.	FEB-27 DEL.	FEB-28 DEL.	MAR-7 DEL.	MAR-14 DEL.	MAR-17 DEL.	MAR-18 DEL.	MAR-23 DEL.	MAR-24 DEL.	MAR-30 DEL.	TOTAL DELIVERED	CONTRACT REQ'T	PARTS REMAIN'G	APRIL-6 PLAND-DEL	APRIL-13 PLAND-DEL	APRIL-20 PLAND-DEL	
1 LINER CAP C405500-B	TRANSIT	0	8	4	0	8	2	4	0	1	1	4	32	59	27	10	10	7	
	PIONEER	0	0	0	0	0	8	0	6	3	3	2	22	22	0	0	0	0	
2 LINER BODY C405498-C	TRANSIT	10	8	4	0	0	7	2	0	9	0	0	40	59	19	10	9	0	
	PIONEER	0	0	0	0	0	4	0	4	4	0	10	22	22	0	0	0	0	
3 STRENGTH MEMBER CAP C405496-C	TRANSIT	4	8	2	0	11	2	0	2	0	0	5	34	63	29	10	10	9	
	PIONEER	0	0	0	0	0	8	0	0	8	0	6	22	22	0	0	0	0	
4 STRENGTH MEMBER BODY C405495-B	TRANSIT	4	8	2	0	10	2	0	1	3	0	4	34	63	29	10	10	9	
	PIONEER	0	0	0	0	0	8	0	0	8	0	6	22	22	0	0	0	0	
5 CLAD CAP C405493-C	TRANSIT	6	0	4	7	9	0	0	0	2	0	0	28	64	36	10	10	16	
	PIONEER	0	0	0	0	0	0	8	0	8	0	6	22	22	0	0	0	0	
6 CLAD BODY C405492-B	TRANSIT	5	0	3	7	10	0	0	0	2	0	0	27	64	37	14	14	9	
	PIONEER	0	0	0	0	0	0	8	0	8	0	6	22	22	0	0	0	0	
7 FUEL LOCATOR RING C405538-NC	TRANSIT	20	0	0	0	10	0	0	0	0	0	0	30	59	29	10	10	9	
	PIONEER	0	0	0	0	0	8	0	0	0	0	14	22	22	0	0	0	0	
8 LINER SHIM C405506-A -1	TRANSIT	0	0	7	0	13	2	0	0	4	0	0	26	59	* 23	10	10	13	
	PIONEER	0	0	0	0	0	8	0	0	0	0	0	8	59	* 51				
	-2 TRANSIT	0	0	7	0	13	2	0	0	15	0	0	37	59	22	10	12	0	
	PIONEER	0	0	0	0	0	8	0	0	14	0	0	22	22	0	0	0		
	-3 TRANSIT	0	0	7	0	13	2	0	0	15	0	0	37	59	22	10	12	0	
	PIONEER	0	0	0	0	0	8	0	0	14	0	0	22	22	0	0	0		
	-4 TRANSIT	0	0	7	0	13	2	0	0	16	0	0	38	59	21	10	11	0	
	PIONEER	0	0	0	0	0	8	0	0	14	0	0	22	22	0	0	0	0	

* NO SHIM STOCK AVAILABLE