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LARGE RADIOISOTOPE HEAT SOURCE
CAPSULE PROGRAM

TOPICAL REPORT NO. 9
TRANSIT CAPSULE THERMAL
VERIFICATION TESTS

MASTER

AEC Research and Development Report

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Atomics International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

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CAPSULE PROGRAM

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VERIFICATION TESTS

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ABSTRACT

This topical report contains the fabrication and assembly history, and the test results for the Transit Thermal Verification Capsule. The thermal verification capsule is an electrically heated mockup from which data were obtained on thermal gradients around individual components and on the ΔT 's between components. Tests were accomplished in both helium and vacuum environments.

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I. INTRODUCTION

The Transit Thermal Verification Capsule consists of an electrical heater incased in a typical transit capsule. The purpose of the test was to provide temperature data for use by Mound Laboratories in verifying capsule assembly and handling procedures, and for use by TRW in verifying capsule design and operation.

Temperature measurements were taken at each stage of assembly of the capsule. Thermocouples were installed on each component to measure the temperature drops of the assembled capsule. The temperature drops were measured as a function of power at 600, 700, 807, and 850 watts in both helium and vacuum environments, and as a function of helium pressure in the gaps between the components.

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II. TEST OBJECTIVES

The objective of this test was to obtain operating temperatures on the Transit capsule components. Both temperature distribution on the individual components and temperature drops between the components were obtained for each stage of the capsule assembly in both helium and vacuum environments. As a secondary objective, an attempt was made on obtaining thermal expansion data on the capsule components.

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III. TEST ARTICLE

The test capsule was assembled from capsule components from the MRC Transit test capsule production order. The capsule components were typical in all materials, dimensional characteristics, coatings, and treatments. The capsule component details and the test capsule assembly are shown in Figures 1, 2, 3, and 4. The internal electrical heater was fabricated from an alumina spool wound with tantalum wire over which was placed a thin alumina sleeve to prevent heater shorting during testing. Heater details are shown in Figures 5, 6, 7, and 8.

The assembled heater, Figure 9, was seal welded into the liner body, Figure 10, and feed-through assembly, Figure 11. The clad cap, junction box, and feed-through flange were then assembled with the feed-through flange being assembled loosely. The liner assembly, Figure 12, was placed in the glove box and, under one atmosphere of ultra high purity helium, the feed-through flange was sealed to retain helium inside the liner assembly.

The liner assembly being complete, the strength member body was assembled and welded to the strength member cap, Figure 13. Three (3) sheathed Pt-Rh thermocouples were then permanently attached to the strength member body as shown in Figure 14.

In the final assembly, the three (3) strength member thermocouples were fed through holes in the clad cap and body, and the cap and body were E. B. welded. At this point the Pt-10Rh sleeve was TIG welded to the clad cap and the Pt-10Rh tube. The Pt-10Rh tube was brazed using "Easy-Flo Number 45" to the stainless steel sleeve. The completed assembly is shown in Figure 15.

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Figure 1. Test Capsule Assembly
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VARIAN FLANGE (MOD)
MAT'L: 304 SST

HOLE LAYOUT

Figure 3. Feed-Thru Flange
Modifications

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CLAD CAP

Figure 4. Clad
Coating Details
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SK-N73413001 'A'

SPOOL ASSY-HEATER
 MAT'L: 99% ALUMINA

Figure 5. Spool Assembly Heater
 AI-AEC-12962
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① MUST CLEAR SPOOL ASSY - .005 TO .010 RADIAL CLEARANCE

SK-N73413002 "B"
 SLEEVE ASSY-HEATER
 MATL: 99% ALUMINA

Figure 6. Sleeve Assembly Heater

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Figure 8.

HEATER TIE BAR PIECE PARTS

Figure 9. Assembled Heater Less Instrumentation

Figure 10. Liner Body with
Thermocouples Attached

Liner Body, Feed-Through Sub-Assembly,
and Heater Ready for Assembly

Figure 11. Assembled and Welded Liner

Figure 12. Liner Assembly Configuration II

Note: Paper Cone is Temporary Protection for Clad Cap

Figure 13. Strength Member Cap Stitch Welded to the Strength Member Cap

Figure 14. Strength Member Assembly - Configuration III

Figure 15. Complete Assembly - Configuration IV
Uncoated Areas in Upper Photo are for Attachment of Thermocouples

IV. TEST SET-UP

The tests were performed in a vacuum glove box, Figure 16, with a volume of approximately 15 cu. ft. and a vacuum capability of 5×10^{-5} torr. The box is instrumented with a Cooke vacuum ion controller with an accuracy of $\pm 5\%$. The test capsule was placed at one end of the box directly opposite one of the two 15-inch viewing ports approximately 4 inches from the floor of the box. The thermocouples attached to the capsule were exited through conax fittings mounted in a glove port cover. The thermocouples were then attached to a terminal strip from which Pt/Pt-10Rh compensated lead was run to a Barber-Coleman temperature recorder calibrated for Pt/Pt-10Rh thermocouples. Two absolute pressure gauges, one with a range of 0 to $200 \pm 0.5\%$ psi and the other with a range of 0 to $800 \pm 0.1\%$ millimeters, were used to read the ultra high purity (99.9999%) helium atmosphere.

Power was controlled to the capsule using a General Radio Company 20 amp "Variac." Power read-outs were calculated from readings taken from a Watson Electric Instrument Corp. ammeter and voltmeter, both capable of $\pm 1\%$ accuracy, and a Watson electrodynamic wattmeter of $\pm 0.25\%$ accuracy which was used for an indication only. The relationship of the glove box, instrumentation feed-throughs and recorders are shown in Figure 17.

Figure 16. Vacuum Glove Box with Vacuum Ion Controller and Absolute Pressure Gauge

Temperature Recorded with Voltmeter, Ammeter,
Wattmeter, and Variac on Top

Figure 17. Thermocouples shown Exiting Glove Port
Cover to Terminal Strip

V. TEST DESCRIPTION AND RESULTS

This section describes each of the tests performed and presents the raw temperature data from each test. The evaluation of the data with regard to validity and consistency, extrapolation of the data, and conclusions based on the test data are contained in Section VI.

A. HEATER ASSEMBLY (CONFIGURATION I)

The heater assembly was placed in the vacuum glove box, Figure 18, and instrumented with three (3) thermocouples. The box was evacuated and back-filled with ultra high purity helium three (3) times. With one (1) atmosphere of helium in the box, power was applied to the heater slowly in increments of 200 watts allowing the heater temperature to stabilize at each input until 850 watts of power was reached. The heater performed satisfactorily.

The heater was removed from the glove box for assembly into the liner. During handling a heater lead wire broke off. Examination of the lead wire showed contamination and embrittlement of the tantalum. A new heater was fabricated, Figure 19, with particular precautions taken in outgassing the alumina parts before assembly. The new heater was placed in the vacuum glove box and instrumented with one (1) thermocouple. With one (1) atmosphere of helium, 80 watts of power was applied to the heater for approximately 50 minutes. This brought the heater temperature to 400 °F to again outgas the heater before assembly. Examination of the heater after this test showed no indication of contamination or embrittlement of the heater wire.

B. LINER ASSEMBLY (CONFIGURATION II)

The liner assembly, Figure 20, was instrumented with ten (10) thermocouples, three (3) being permanent sheath thermocouples mounted on the inside of the liner and seven (7) being temporary thermocouples attached at various points on the outside of the assembly. The T/C's are identified in Figure 21.

Figure 18. Heater

Figure 19. Second Heater Before Testing in Glove Box

FIGURE 20
LINER ASSEMBLY (CONFIGURATION II)
THERMOCOUPLE LOCATIONS

Calibration No.	Test No.	Location	Temp. Rec. Ident. No.
T-70013 No. 1	LTTC No. 3	Bottom outside of liner body	7
T-70013 No. 2	LTTC No. 1	Outside of liner body - 1.16 from edge of strength mem. cap - in line with LTC No. 1	5
T-70013 No. 3	LTTC No. 2	Outside of liner body - 2.36 from edge of strength mem. cap - in line with LTC No. 2	6
T-70016 No. 4	LTC No. 3	Bottom inside of liner body	4
T-70016 No. 5	LTC No. 2	Inside of liner body - 2.36 from edge of strength mem. cap	3
T-70016 No. 6	LTC No. 1	Inside of liner body - 1.16 from edge of strength member cap	2
T-70016 No. 1	Not in Test Plan	On Feed-thru tube - 5.10 from dome of strength member cap	10
T-70016 No. 2		On Feed-thru tube - 3.40 from dome of strength member cap	9
T-70016 No. 3		On Feed-thru tube - 1.70 from dome of strength member cap	8
Not Calibrated		On Conax fitting - (feed-thru flange)	11

Figure 21. Liner Assembly (Configuration II) Thermocouple Identification Chart

The assembly was then placed in the vacuum glove box with the junction box resting on a copper chill block and the capsule on a "glass rock" "V" block as shown in Figure 22. A three (3) layer tantalum heat shield was placed around the feed-through tube, close to the junction box, and the glove box sealed and pumped down to a vacuum of 7.5×10^{-5} torr.

At this point an attempt was made to index the capsule diameter at a specific location by using a cathometer. This was the method to be used to check the thermal growth at the various temperatures. Due to vibration of the glove box, caused by the vacuum pump, meaningful data could not be obtained.

Power was applied slowly until the first reference input of 600 watts was reached and the capsule temperature stabilized. The power was then increased to 700, 807, and 850 watts, with the temperature allowed to stabilize at each reference wattage input. The liner assembly at 850 watts in vacuum is shown in Figure 23. Temperature, power, and vacuum readings were recorded at each reference point. The capsule was allowed to cool down to approximately 600 °F before the glove box was back-filled with ultra high purity helium. With the glove box atmosphere at 14.7 psi of helium, power was applied slowly to the first reference point, 600 watts. The same procedures as described for the vacuum test were duplicated in the helium test.

The temperatures at various locations on the capsule versus the power input are shown in Figures 24 and 25. Figure 24 shows the temperature distribution for the vacuum test. Examination of this data indicates that thermocouples Number 5, Number 6, and Number 7 were not recording true liner temperatures. The readings of thermocouples Number 2 and Number 5, Number 3 and Number 6, and Number 4 and Number 7 should almost be identical. This problem was probably due to poor contact between the thermocouple junction and the liner body for the external thermocouples. A more detailed discussion of this data is contained in Section VI.

Figure 25 is a chart of the temperatures during the helium test. Again primary thermocouples, Number 2, Number 3, and Number 4 appear to provide true readings while the data from the external T/C's is clearly suspect. See Section VI.

Figure 22. Liner Assembly (Configuration II) in Vacuum Glove Box at Start of Test

Figure 23. Liner Assembly During Vacuum Test -
Input 850 watts - Temperature 1925 °F

Figure 24. Liner Assembly Vacuum Test
Power vs. Temperature

Figure 25. Liner Assembly Helium Test, Power vs. Temperature

FIGURE 26
STRENGTH MEMBER ASSEMBLY (CONFIGURATION III)
THERMOCOUPLE LOCATIONS

C. STRENGTH MEMBER ASSEMBLY (CONFIGURATION III)

The strength member assembly was instrumented with ten (10) thermocouples. Six (6) of the T/C's were permanent sheath type, three (3) on the inside of the liner and three (3) on the outside of the strength member. The remaining four (4) thermocouples were temporary with three (3) located on the strength member and one (1) on the feed-through flange. The T/C location and identification are shown in Figures 26 and 27.

The same basic test set-up was used for the strength member assembly as described in the liner assembly test. The chill block, heat shield and "glass rock" were used as shown in Figure 28. The first test was started in a vacuum of 5.0×10^{-5} torr. In this and subsequent vacuum tests the power input was limited to hold the temperature of the liner body below 1900 °F so as not to overheat the heater assembly.

Power was applied and increased from an initial input of 100 watts to 383 watts with no attempt at temperature stabilization except at 383 watts. At this input, the strength member thermocouples recorded a high of 1405 °F and the highest temperature recorded by the liner thermocouples was 1915 °F. The power was turned off and the vacuum portion of the test was terminated.

After the capsule had cooled down to approximately 700 °F, the glove box was back filled with helium to 14.7 psi and power applied slowly to bring the capsule to the first reference wattage input of 600 watts. After approximately 35 minutes at 600 watts input, the "glass-rock" support block fractured at the bottom of the "V" slot, allowing the end of the capsule to rest on the floor of the glove box as seen in Figure 29. The power was turned off and the capsule placed on a new block of "glass-rock" and the temporary thermocouples Number 5, Number 6, and Number 7 were re-tightened. The test was re-started with a helium pressure of 14.5 psi. Power was again applied slowly to bring the capsule to stabilized temperatures at the reference wattage inputs of 600, 700, 807, and 850 watts.

There was some question as to the validity of the temperatures due to the restriction of heat dissipation in the area of contact between the capsule and support block. Both the vacuum and helium tests were rerun with the capsule suspended by a 0.060-inch diameter tantalum wire as shown in Figure 30.

Calibration No.	Test No.	Location	Temp. Rec. Ident. No.
T-70016 No. 6	LTC No. 1	Inside of Liner - 1.36 from edge of clad cap	2
T-70016 No. 5	LTC No. 2	Inside of Liner - 2.36 from edge of clad cap	3
T-70016 No. 4	LTC No. 3	Bottom inside of liner body	4
T-70016 No. 1	SMTC No. 1	Outside of strength mem. body 1.36 from edge of clad cap in line with LTC No. 1	8
T-70016 No. 2	SMTC No. 2	Outside of strength mem. body 2.36 from edge of clad cap in line with LTC No. 2	9
T-70016 No. 3	SMTC No. 3	Bottom outside of strength mem. body - in line with LTC No. 3	10
T-70013 No. 2	SMTC No. 1	Outside of strength mem. body in line and midway between SMTC No. 1 and SMTC No. 2	5
T-70013 No. 3	SMTTC No. 2	Outside of strength mem. body at tangent of spherical radius - in line with SMTC 3	6
T-70013 No. 1	SMTTC No. 3	Bottom outside of strength mem. body - adjacent to SMTC No. 3	7
Not Calibrated	Not in Test Plan	On Feed-thru flange close to Conax fitting	11

Figure 27. Strength Member Assembly (Configuration III) Thermocouple Identification Chart

Figure 28. Strength Member Assembly (Configuration III) in Vacuum Glove Box at Start of Test

Figure 29. Strength Member Assembly Resting on Floor of Glove Box with Broken Support Block

Figure 30. Strength Member Assembly Suspended

Figure 31. Strength Member Assembly During Helium Test - Input 850 Watts - Temp. 1290 °F

Figure 32. Strength Member Assembly During Vacuum Test - Input 299 watts - Temperature 1250 °F

The first test of the suspended straight member assembly was in a helium atmosphere of 14.4 psi. Power was applied and the same basic test parameters of temperature stabilization at the reference wattage inputs of 600, 700, 807, and 850 watts were followed. The capsule at 850 watts is shown in Figure 31.

At the conclusion of the helium test, the glove box was pumped down to a vacuum of 5.8×10^{-5} torr. Power was applied and increased to 299 watts. The maximum temperature recorded on the liner was 1770 °F with 1250 °F on the strength member. Figure 32 shows the capsule at this condition. Power was then turned off, concluding the strength member assembly tests.

Figures 33 and 34 show the temperature versus power input for the capsule resting on a block of "glass-rock," and Figures 35 and 36 show temperature versus power for the suspended capsule.

Figure 33 shows a temperature differential of approximately 500 °F from the inside of the liner (helium atmosphere) to the outside of the strength member with a vacuum in the gap between the liner and strength member and a fixed power input of 383 watts. Figure 34 shows the temperatures for the helium test.

Figure 35 shows the re-run of the strength member assembly in vacuum but suspended. Although the test was performed with a lower power, 299 watts versus 383 watts, the temperature spread is approximately the same as plotted in Figure 33.

Figure 36 is a temperature vs. power plot of the suspended strength member assembly in helium. All of the permanent thermocouples, Number 2, Number 3, Number 4, and Number 8, Number 9, and Number 10, responded as expected. By reducing the support contact area, each thermocouple recorded approximately a 25 °F lower temperature. Again the readings from thermocouples Number 5, Number 6, and Number 7 are not considered valid.

D. FINAL ASSEMBLY (CONFIGURATION IV)

The complete assembly was instrumented with twelve (12) thermocouples. Six (6) thermocouples were of the permanent sheath type, of which three (3) were on the inside of the liner and three (3) on the outside of the strength member. The remaining six (6) thermocouples were spot welded to the clad body. The T/C identification and locations on the assembly are shown in Figures 37, 38, and 39.

Figure 33. Strength Member Assembly Vacuum Test
Power vs. Temperature

Figure 34. Strength Member Assembly Helium Test
Power vs. Temperature

Figure 35. Suspended Strength Member Assembly Vacuum Test
Power vs. Temperature

Figure 36. Suspended Strength Member Assembly Helium Test
Power vs. Temperature

FIGURE 37
COMPLETE ASSEMBLY (CONFIGURATION IV)
THERMOCOUPLE LOCATIONS

Calibration No.	Test No.	Location	Temp. Rec. Ident. No.
T-70016 No. 6	LTC No. 1	Inside of liner body - 1.16 from weld joint	2
T-70016 No. 5	LTC No. 2	Inside of liner body - 2.36 from weld joint	3
T-70016 No. 4	LTC No. 3	Bottom inside of liner body	4
T-70016 No. 1	SMTC No. 1	Outside of strength member 1.16 from weld joint	7
T-70016 No. 2	SMTC No. 2	Outside of strength member 2.36 from weld joint	6
T-70016 No. 3	SMTC No. 3	Bottom outside of strength member	5
T-70032 No. 3	CTC No. 1	Outside of clad - 1.16 from weld joint	8
T-70032 No. 1	CTC No. 2	Outside of clad - 2.36 from weld joint bottom	9
T-70032 No. 2	CTC No. 2	Outside of clad	10
T-70013 No. 3	CTTC No. 1	Outside of clad - .50 from weld joint	12
T-70013 No. 2	CTTC No. 2	Outside of clad - 1.90 from weld joint	11
T-70013 No. 1	CTTC No. 3	Outside of clad - 35° from $\odot$	13

Figure 38. Complete (clad) Assembly (Configuration IV) Thermocouple Identification Chart

Figure 39. 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.

The first test of the complete assembly was in a vacuum and the capsule was supported by a 0.060-inch thick tantalum "V" block as seen in Figure 40. Power was applied and increased slowly to 392 watts. At this point the temperature was allowed to stabilize and readings taken. Again, the test was terminated due to the liner temperature reaching the 1900 °F limit. Approximately 30 minutes before test termination, thermocouple number 13 broke loose as seen in Figure 41.

The capsule was allowed to cool down in the glove box to approximately 600 °F and then back-filled with helium to 14.6 psi. Power was then applied to the capsule in 200-watt increments until the first reference power input of 600 watts was reached and the temperature stabilized. The power was increased and the temperature allowed to stabilize at each reference wattage input of 700, 807, and 850 watts. Figures 42 and 43 show the temperatures at various power inputs in both helium and vacuum atmospheres in the gaps between piece parts.

E. VARIABLE PRESSURE TEST (CONFIGURATION IV)

The purpose of the final test was to find the approximate helium pressure required to produce a significant drop in the temperature differential between components at a constant power input.

The test started with the capsule in a vacuum of 3.8×10^{-5} torr (see Figures 37 and 38 for thermocouple locations). Power was applied slowly until power of approximately 400 watts was reached and the capsule temperature stabilized. Helium was then bled into the glove box in stages, allowing the helium pressure and capsule temperature to stabilize at each stage.

Figure 44 shows temperature versus pressure at the constant power input of 410 watts. From this test, it appears that the breakaway pressure is in the range of 50 millimeters of mercury or about one psia. With the exception of thermocouples Number 11 and Number 12, all recorded temperatures appear accurate.

Figure 40. Complete (clad) Assembly (Configuration IV)
in Vacuum Glove Box at Start of Test

Figure 41. Complete Assembly with Thermocouple
Number 13 Loose

Figure 42. Complete (clad) Assembly Vacuum Test
Power vs. Temperature

Figure 43. Complete (clad) Assembly Helium Test
Power vs. Temperature

Figure 44. Complete (clad) Assembly
Vacuum to Helium Test
Temperature vs. Pressure
(See Figure 37)

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VI. TEST DATA ANALYSIS AND CONCLUSIONS

Verification of the validity of the test data was accomplished by analyzing the set of results relating to each of the individual component tests and then demonstrating consistency among the various sets.

The temperature measurements taken on the surface of the feed-thru tube during the liner assembly vacuum tests were used to determine the feed-thru tube losses as a function of the power input. The line losses to the junction box were also accounted for by determining the I^2R losses from the voltage and current readings at each of the power levels. These losses, as a function of power input, are shown in Figure 45. The net energy to the component assembly was then determined as the difference between the total power input and the sum of the losses.

The mode of heat transfer for dissipation of heat into vacuum is strictly by radiation. The heat balance equation for the liner assembly vacuum test may therefore be expressed as

$$Q_{\text{net}} = \frac{\sigma (T_{\text{lo}}^4 - T_{\text{gb}}^4)}{\frac{1 - \epsilon_{\text{lo}}}{\epsilon_{\text{lo}} A_{\text{lo}}} + \frac{1}{A_{\text{lo}} F_{\text{lg}}} \frac{1 - \epsilon_{\text{gb}}}{\epsilon_{\text{gb}} A_{\text{gb}}}} \quad (1)$$

where:

- σ = Stefan-Boltzmann Constant = $0.1713 \times 10^{-8} \frac{\text{Btu}}{\text{ft}^2 \cdot \text{hr} \cdot (^\circ\text{R})^4}$
- T = Temperature, $^\circ\text{R}$
- ϵ = Surface emissivity
- A = Surface Area, ft^2
- F_{lg} = View factor between the liner assembly and the glove box = 1

The subscripts "lo" and "gb" pertain to the liner outer surface and the glove box inner surface, respectively. Since the surface area of the glove box is significantly greater than that of the liner assembly, and the view factor between the liner assembly and the glove box is unity, equation (1) may be reduced to:

$$Q_{\text{net}} = A_{\text{lo}} \epsilon_{\text{lo}} \sigma (T_{\text{lo}}^4 - T_{\text{gb}}^4) \quad (2)$$

Since the heat transfer by radiation is proportional to the fourth power of the surface absolute temperature, the effect of glove box temperature is of minor significance and was therefore neglected. Equation (2) was used to solve for the liner outer surface emissivity by utilizing the two liner temperature measurements, T/C No.'s 2 and 3, on the cylindrical portion, and the temperature measurement at the end, T/C No. 4 (Figure 24). An estimate of the effective liner temperature at the other hemispherical end, adjacent to the feed-thru tube, was obtained from the readings of T/C No.'s 8, 9, and 10, on the feed-thru tube, and T/C No.'s 2 and 3 on the liner body. As pointed out in Section V, T/C No.'s 5, 6, and 7 were not recording true temperatures (see Figure 24) due to poor contact between the thermocouple junction and the liner body. These readings were therefore discarded for analysis. The values of ϵ_{lo} derived, by using the inner T/C's on the liner assembly, range between 0.20 and 0.23.

A similar approach was used for deriving the emissivity of the outside surface of the strength member body, ϵ_{SMO} . Since the vacuum tests were conducted at a single power level, one value for ϵ_{SMO} (0.23) was obtained. The same approach was applied to the analysis of the complete (clad) assembly in confirming a surface emissivity of 0.85 for the outer clad. However, the procedure was not as straightforward since it was determined (as subsequently discussed) that the outer clad was in physical contact with the strength member at a portion of the bottom surface and the flux field had to be defined before an estimate of the effective temperature at the other hemispherical end could be determined.

Based upon the data obtained from the Suspended Strength Member Assembly Vacuum Tests, Figure 35, the emissivity of the inside surface of the strength member assembly was determined. Equation (3) below was used which represents the relationship involving the radiant interchange between the outside surface of the liner and the inside surface of the strength member.

$$Q_{lo-smi} = \frac{\sigma(T_{lo}^4 - T_{smi}^4)}{\frac{1 - \epsilon_{lo}}{\epsilon_{lo} A_{lo}} + \frac{1}{A_{lo} F_{l-sm}} + \frac{1 - \epsilon_{smi}}{\epsilon_{smi} A_{smi}}} \quad (3)$$

Where ϵ_{smi} is the emissivity of the inside surface of the strength member.

The surfaces were divided into regions corresponding to the location of the temperature measurement and the amount of radiant interchange was computed for each region. A value of 0.35 for ϵ was obtained by this method. Determination of this value was subsequently confirmed when excellent agreement was obtained after conducting a similar analysis for the data shown in Figure 42, which are the results of the vacuum tests conducted on the complete (clad) assembly. Agreement within 3% was also obtained for the complete (clad) assembly test data of Figure 44 at vacuum conditions.

The same technique was attempted for the emissivity of the inside surface of the outer clad. However, this was unsuccessful inasmuch as the data of Figure 42 indicated that a value greater than unity would be necessary in order to transfer the required amount of heat by radiation between the two surfaces. It appears that, in addition to radiation, another mode of heat transfer existed between the strength member and the outer clad. Since convection is not possible at vacuum conditions, conduction must have occurred, implying that the two surfaces were in physical contact. Since the assembly was in a horizontal position, supported from the bottom, contact between the strength member and the clad, along a portion of the bottom away from the feed-thru tube end, can be expected. Analysis of the data of Figure 44 appears to further substantiate this hypothesis. If one considers the average heat flux over the entire capsule on the basis of heat input and overall surface area, a value of approximately 5000 Btu/hr-ft^2 is obtained. When computing the local heat flux at the various T/C locations on the outer clad at vacuum conditions, values of 3600, 3100, and 7900 Btu/hr-ft^2 are obtained based upon the temperatures corresponding to T/C No.'s 8, 9, and 10 respectively. It can be seen upon examining Figure 46 that the average radiative heat flux based upon the three aforementioned T/C's is below the average value computed on the basis of net heat input and surface area. At the same time the average radiative heat flux between the inner clad and the strength member appears to coincide with average obtained from heat input and surface area. This implies that a greater than average heat flux distribution must have prevailed on the bottom side. This condition would be induced from the higher temperature that existed at the bottom side when the clad surface assumed a higher temperature due to physical contact with the strength member body.

This also offers an explanation for the high reading and high local heat flux obtained at T/C No. 10. Heat conduction took place between the underside of the capsule and the end due to the temperature gradient established as a result of this contact. The total heat leaving the end was therefore a combination of the heat received directly from the strength member by radiation and that received by conduction from the portion of the outer clad which was in contact with the strength member at the underside of the capsule.

Analysis of the helium test data displayed in Figures 25, 34, and 43 was conducted for the liner, strength member, and complete (clad) assemblies respectively. In view of the significantly lower surface temperatures experienced, estimates of the surface emissivities were made. When a value of 0.85 is used for the outside surfaces of the complete (clad) assemblies, convective heat transfer coefficients between 4.2 and 5.9 Btu/hr-ft² - °F are obtained. When compared with the correlation recommended by McAdams for single horizontal cylinders

$$\text{Nu} = 0.53 D^{0.75} \Delta T^{0.25} [\text{Gr Pr}]^{0.25} \quad (4)$$

where

D = Diameter of cylinder

T = Film temperature drop

Nu = Nusselt number

Gr = Grashof number

and Pr = Prandtl number

it is found that the results are from 17 to 40 percent higher than those obtained by the use of Equation (4). The difference may be attributed to the hemispherical end effects.

Based upon the helium test data of Figure 44, the combined local heat flux due to both radiation and convection was computed and is shown by the broken line in Figure 46. It will be noticed that the average of the local heat flux distribution on the top side is slightly lower than the overall average obtained on the basis of heat input to the assembly. This implies that both the average heat flux on the underside must be higher as well as the temperature distribution. This follows from the previous conclusion that

was reached that higher temperatures resulted from the strength member body being in physical contact with the outer clad. Referring to Figure 43, it will be noticed that relatively large temperature differences exist between the surfaces of the liner and strength member, and the strength member and outer clad for the amount of heat that is being transferred by conduction. When considering the fact that the gap width at the top side is probably doubled as a result of the tests being conducted with the unit in the horizontal position, the amount of heat being transferred by conduction may be accounted for. Similarly, at the bottom side the surfaces were in physical contact over some portion of the area, the surface temperatures of the clad, strength member and liner bodies tend to approach each other thus resulting in a temperature gradient compatible with the decreased effective gap widths on the lower side. Thus, what would appear to be large temperature gradients for the amount of heat being dissipated can be accounted for by circumferential temperature gradients. For the above reasons the liner and strength member temperatures recorded in these tests (along top of capsule) are most likely the maximum temperatures on those components.

It is concluded that the values for the surface emissivities derived on the basis of the vacuum tests are valid in view of the consistency found among the different sets of data. In addition, the temperature readings and the heat dissipation can be accounted for in the complete (clad) assembly tests for both the vacuum and helium conditions. Therefore, the recorded temperatures are considered correct for the indicated locations. Finally, while the ΔT 's between components in the vacuum to helium test (Figure 44) cannot be considered averages because of the circumferential gradients, the variations of ΔT with pressure are accurate and can safely be used in calculating system temperatures as a function of helium backpressure.

Figure 45.
POWER LOSSES VS. POWER INPUT
FOR
LINER ASSEMBLY VACUUM TESTS

NOTE:

1. FEED-THRU TUBE LOSS
BASED ON SURFACE
EMISSIVITY = 0.2
2. LINES OF 12 GAGE COPPER
TWO - 5 FT. LENGTHS

Figure 46.

ASSEMBLY HEAT FLUX

[DATA FROM FIGURE 44]

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APPENDIX

A. DISPOSITION OF TEST ARTICLE

The Transit thermal verification test capsule was packaged and delivered to TRW on April 7, 1970. It was recommended to TRW that the test capsule be stored in ultra high purity helium until ready for further tests.

B. DIMENSIONAL DATA

Figures B1 through B6 are the dimensional inspection reports and Figure B7 the assembly clearance data for the test capsule which consisted of the following serial numbered parts:

- S/N 045 - Liner Cap
- S/N 047 - Liner Body
- S/N 033 - Strength Member Cap
- S/N 012 - Strength Member Body
- S/N 031 - Clad Cap
- S/N 019 - Clad Body

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TRANSIT - CAPSULE
DIMENSION INSPECTION DATA RECORD

PART NAME Heat Source Liner Cap
PART NUMBER C405500A
MPO NUMBER 2004002
MATERIAL TA-10W

CHART 6

MATERIAL REVIEW APPROVALS

Q&RA: _____ DATE: _____
PROGRAM MANAGER _____ DATE: _____

SERIAL NO	PART RESTRAINED ON LATHE								PART UNRESTRAINED								FINAL DISPOSITIONS			
	A	B	C	D	E	F	G	H	I	J	K	L	T ₁	T ₂	T ₃	T ₄	—	INSPECTION STAMP INDICATING FINAL DISPOSITION	(1) ACCEPT, (2) REJECT, (3) MFC REVIEW, (4) EXCEPTION	WITHHELD STATUS
045																				
046																				
047	2.2045	2.1620	.0148	.7500	.0008	.0010	1.1370	1.0988	.0006	.0040	.0020	.0005	.032	.0315	.0350	.0347		1.07	.007	.0005
048	2.2050	2.1615	.0145	.7500	.0010	.0010	1.1440	1.0942	.0005	.0040	.0030	.0005	.0311	.0294	.0350	.0345		1.206	.013	.0000
049	2.2050	2.1619	.0146	.7502	.0009	.0010	1.1356	1.0907	.0007	.0050	.0030	.0005	.0310	.0307	.0355	.0345		1.206	.008	.0005
050	2.2034	2.1620	.0154	.7495	.0008	.0008	1.1380	1.0967	.0006	.0040	.0030	.0005	.0300	.0292	.0355	.0340		1.206	.008	.0005
051	2.2055	2.1620	.0155	.7495	.0010	.0009	1.1337	1.0989	.0010	.0040	.0020	.0015	.0312	.0297	.0350	.0338		1.207	.008	.0005
052	2.2046	2.1623	.0135	.7498	.0007	.0008	1.1270	1.0905	.0007	.0040	.0030	.0005	.0308	.0290	.0346	.0339		1.206	.005	.0005
053	2.2056	2.1619	.0145	.7502	.0010	.0010	1.1368	1.0944	.0008	.0040	.0020	.0010	.0306	.0299	.0355	.0340		1.207	.009	.0010
054	2.2047	2.1617	.0152	.7504	.0010	.0010	1.1424	1.0941	.0008	.0050	.0020	.0005	.0302	.0296	.0350	.0337		1.206	.008	.0005
055	2.2020	2.1617	.0150	.7496	.0009	.0010	1.1410	1.0951	.0006	.0040	.0040	.0010	.0293	.0279	.0340	.0332		1.207	.007	.0005
056	2.2050	2.1615	.0145	.7495	.0006	.0008	1.1415	1.0949	.0006	.0050	.0020	.0010	.0312	.0294	.0342	.0335		1.207	.006	.0005

0.005 ± .002 R
SHARP 0.003 MAX. R
OUTSIDE STRAIGHT SECTION
INSIDE STRAIGHT SECTION
0.104 ± .005
0.104 ± .005 ± 0.015 ± 0.005

Figure B-1
AI-AEC-12962
75

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CHART 5

DASH NO.: 2

MATERIAL: TA-10W

PROGRAM MANAGER _____ DATE: _____

Figure B-2
AI-AEC-12962
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PART NAME: Strength Member Cap
PART NUMBER: TRW C405496A
MPO NUMBER: 2003102
MATERIAL: T-111

TRANSIT - CAPSULE
DIMENSION INSPECTION DATA RECORD

CHART 4

MATERIAL REVIEW APPROVALS

Q&RA: None DATE: 11/20/70
PROGRAM MANAGER: W. J. ... DATE: 11/2/72

PART RESTRAINED ON LATHE											PART UNRESTRAINED														FINAL DISPOSITION					
SERIAL NO.	A	B	C	D	E	F	G	H	I	J [#]	K	L	M	N	O	P	Q	R	S	T ₁	T ₂	T ₃							COMMENTS	
033	2.4005	2.3239	2.2410	0010	0012	0004	1.3198	0500	0099	—	NO HOLES DRILLED	—	—	0006	0005	0050	0040	0020	0010	0020	0935	0839	0935	—	—	—	—	—	—	Taken for Thermal Test
034	2.4013	2.3250	2.2414	0004	0006	0006	1.3211	0486	0102	—	—	—	0007	0002	0020	0040	0020	0010	0020	0936	0884	0932	OK	—	—	—	—	—	—	007 STEP 5 RADI. IS NOT TRUE
035	2.4010	2.3245	2.2418	0005	0007	0007	1.3187	0490	0100	1.201	16°/.012 WALL	14°/.012 WALL	0008	0010	0015	0050	0020	0010	0015	0940	0899	0926	OK	—	—	—	—	—	—	IDR 04705
036	2.4012	2.3238	2.2428	0005	0006	0003	1.3187	0498	0100	1.201	14 1/2°/.012 WALL	14 1/2°/.014 WALL	0007	0005	0020	0050	0020	0020	0020	0930	0908	0917	OK	—	—	—	—	—	—	" 04705
037	2.4017	2.3246	2.2417	0007	0008	0005	1.3191	0494	0102	1.201	15°/.013 WALL	14°/.012 WALL	0005	0010	0025	0040	0020	0020	0015	0941	0910	0928	OK	—	—	—	—	—	—	" 04705
038	2.4013	2.3240	2.2414	0004	0005	0006	1.3173	0500	0100	—	—	—	0004	0005	0025	0050	0020	0020	0020	0907	0890	0905	—	—	—	—	—	—	—	CHECK APPARENT - VISIBLE LONG COMPARED WITH PART
039	2.4014	2.3252	2.2418	0006	0007	0004	1.3217	0500	0000	—	—	—	0006	0005	0010	0060	0020	0008	0010	0930	0898	0905	—	—	—	—	—	—	—	"
040	2.4012	2.3243	2.2419	0005	0007	0007	1.3218	0497	0099	1.201	15°/.013 WALL	15°/.013 WALL	0010	0010	0015	0040	0020	0005	0010	0928	0910	0940	OK	—	—	—	—	—	—	IDR 04705
041	2.4026	2.3245	2.2415	0003	0006	0009	1.3187	0460	0093	—	—	—	0008	0005	0020	0040	0020	0010	0010	0930	0907	0926	OK	—	—	—	—	—	—	"
042	2.4011	2.3243	2.2419	0004	0005	0007	1.3210	0518	0100	1.201	15°/.013 WALL	14°/.016 WALL	0009	0010	0020	0050	0020	0020	0010	0930	0900	0940	OK	—	—	—	—	—	—	IDR 04705
043	2.4010	2.3246	2.2416	0003	0005	0008	1.3198	0488	0100	—	—	—	0008	0010	0020	0040	0020	0020	0010	0940	0901	0932	OK	—	—	—	—	—	—	R HAS .0015 STEP
044	2.4003	2.3248	2.2416	0007	0008	0008	1.3197	0470	0096	—	—	—	0010	0005	0020	0050	0020	0010	0015	0932	0886	0934	OK	—	—	—	—	—	—	R HAS .0020 STEP
045	2.4020	2.3247	2.2418	0004	0005	0007	1.3217	0502	0093	1.201	14°/.012 WALL	15°/.013 WALL	0009	0010	0030	0050	0020	0010	0015	0928	0905	0938	OK	—	—	—	—	—	—	IDR 04705
046	2.4010	2.3245	2.2415	0004	0006	0008	1.3217	0510	0100	1.201	16°/.012 WALL	14°/.014 WALL	0007	0010	0030	0050	0020	0020	0020	0937	0880	0938	OK	—	—	—	—	—	—	" "
047	2.4005	2.3240	2.2420	0007	0009	0008	1.3203	0475	0100	1.201	15°/.014 WALL	15°/.013 WALL	0009	0010	0020	0040	0020	0020	0020	0938	0900	0936	OK	—	—	—	—	—	—	" "
048	2.4016	2.3239	2.2416	0007	0008	0010	1.3201	0487	0102	1.201	14°/.011 WALL	15°/.011 WALL	0007	0010	0030	0060	0020	0020	0030	0928	0906	0930	OK	—	—	—	—	—	—	" "
049	2.4020	2.3241	2.2412	0006	0008	0007	1.3190	0490	0097	1.201	15°/.011 WALL	15°/.014 WALL	0006	0010	0010	0040	0010	0010	0030	0940	0905	0934	OK	—	—	—	—	—	—	" "
050	2.4017	2.3253	2.2416	0004	0006	0006	1.3199	0510	0098	—	—	—	0009	—	—	—	—	—	—	0928	0907	0928	OK	—	—	—	—	—	—	—
051	2.4016	2.3242	2.2416	0004	0005	0006	1.3192	0500	0095	—	—	—	0007	—	—	—	—	—	—	0937	0899	0901	OK	—	—	—	—	—	—	—
052	2.4015	2.3242	2.2427	0005	0007	0008	1.3214	0510	0104	—	—	—	0006	—	—	—	—	—	—	0940	0886	0923	OK	—	—	—	—	—	—	—
053	2.4018	2.3240	2.2418	0003	0006	0008	1.3206	0496	0102	—	—	—	0008	—	—	—	—	—	—	0928	0902	0932	OK	—	—	—	—	—	—	—

Note: machining tool marks visible in surfaces of all parts

Weld prep Radii checked using Contour Reader

* OUTSIDE SPHERICAL RADIUS R used by Tolerances Chart Overlay on IV Comparator

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MATERIAL: T 111

DASH NO. - 2 31

CHART 3

MIR 20424

MATERIAL REVIEW APPROVALS

Q&RA 1/21/19 DATE: 12/1/19

PROGRAM MANAGER G. A. [Signature] DATE: 11/3/69

[illegible]

Figure D-4
AI-AEC-12962
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PART NAME: Clad Capsule Cap
PART NUMBER: TRW C405493A
MPO NUMBER: 400333
MATERIAL: PT-20 Rm

MATERIAL REVIEW APPROVALS

Q&RA: L. Stone DATE: 12/19/69

PROGRAM MANAGER E. R. [Signature] DATE: 12-16-69

MR 20000										PART RESTRAINED										PART UNRESTRAINED										FINAL DISPOSITION																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
										OUTSIDE DIAMETER 2.460 ± 0.003										STEPPED DIAMETER 2.440 ± 0.001										MACHINE CLEANUP 0.100 ± 0.010										CONCENTRICITY ± 0.002 DIAMETER										STEPPED HEIGHT 1.341 ± 0.003										STEP 0.013 ± 0.001										CIRCUMFERENTIAL DIMPLE RADIUS 0.50 ± 0.010										DIMPLE ANGULAR LOCATION 120° ± 0°30'										RADIUS 0.25 ± 0.010										ANGLE 60° ± 0°30'										NORMALITY 0.001 MAX										VISUAL EXAMINATION OF MACHINED SURFACES SHARP 0.004 R MAX										THICKNESS AT EDGE 0.020 ± 0.001										THICKNESS AT EDGE 0.020 ± 0.001										THICKNESS 0.020 ± 0.004										THICKNESS 0.020 ± 0.004										THICKNESS 0.003 ± 0.001										PENETRANT INSPECTION OF EXTERNAL SURFACE AND MACHINED EDGE										INSPECTION STAMP INDICATING FINAL DISPOSITION										(1) ACCEPT, (2) REJECT, (3) MRC REVIEW, (4) EXCEPTION										WITHHELD STATUS										SHARP CORNER										SHARP CORNER .004 MAX. R																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
SERIAL NO.	A	B	C	D	E	F	G	H	I	J	K	N	T ₁	T ₂	T ₃	T ₄	T ₅																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						</

Figure B-5
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TRANSIT - CAPSULE
DIMENSION INSPECTION DATA RECORD

PART NAME: Clad Capsule Body

PART NUMBER: TRW C405492A B

DASH NO. 2

MPO NUMBER: 200/201

MATERIAL: PT-20 RH SHEET.

CHART 1

IDR 04701
MR 20408

MATERIAL REVIEW APPROVALS

Q&RA: _____ DATE: 1-9-70
PROGRAM MANAGER _____ DATE: 1/9/70

MR 20408		PART RESTRAINED ON LATHE							PART UNRESTRAINED														FINAL DISPOSITIONS			
SERIAL NO.	A	B	C	D	E	F	G	H	I	J	K	L	M	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇						COMMENTS
	OUTSIDE DIAMETER 2.460 ± 0.003	STEPPED DIAMETER 2.4425 ± 0.0010	STRAIGHTNESS (FLATNESS) 0.001	CONCENTRICITY 0.002 MAX	LENGTH (L) 5.393 ± 0.002	STEPPED HEIGHT 0.015 ± 0.001	OUTSIDE SPHERICAL RADIUS 1.230 ± 0.0015	NORMALITY 0.002 MAX	CYLINDERICITY (OD ONLY) 0.004 MAX	SHARP EDGE 0.003 R (MAX)	SHARP EDGE 0.003 R (MAX)	0.005 ± 0.001 R	0.004 R (MAX)	WALL THICKNESS (MAX) 0.020 ± 0.001	WALL THICKNESS (MAX) 0.020 ± 0.001	WALL THICKNESS (MIN) (SPHERICAL END) 0.020 ± 0.004	WALL THICKNESS (MAX) (SPHERICAL END) 0.020 ± 0.004	WALL THICKNESS (MIN) (SPHERICAL END) 0.020 ± 0.004	WALL THICKNESS (MAX) (SPHERICAL END) 0.020 ± 0.004	WALL THICKNESS (MIN) (SPHERICAL END) 0.020 ± 0.004	PENETRANT INSPECTION OF ALL SURFACES	INSPECTION STAMP FINAL DISPOSITION	(1) ACCEPT, (2) REJECT, (3) MRC REVIEW, (4) EXCEPTION	WITHHELD STATUS		
Q17	2.4580	2.4426	0010	0009	4.3250	0.151	1.2290	0005	0029"	0010	0010	0040	0020	0.205	0.196	0.238	0.207	0.280	0.272	0.275	OK		1			
Q18	2.4620	2.4424	0009	0010	4.3242	0.153	1.2310	0003	0025"	0020	0010	0045	0020	0.205	0.198	0.234	0.198	0.278	0.270	0.264	OK		1			
Q19	2.4618	2.4423	0008	0006	4.3246	0.148	1.230"	0004	0021"	0020	0020	0040	0030	0.192	0.185	0.228	0.206	0.276	0.270	0.272	NOTED		4 (REV)		REF ID: Q1701- GAUGE ON OD 2 1/2" FROM FACE, 1/32" LONG, R. 103000	
Q20	2.4612	2.4422	0008	0016	4.3218	0.144	1.230"	0005	0035"	0030	0020	0040	0020	0.204	0.195	0.240	0.208	0.281	0.274	0.273	OK		1			
Q21	2.4605	2.4424	0010	0018	4.3245	0.148	1.230"	0002	0038"	0040	0020	0040	0020	0.203	0.196	0.244	0.205	0.280	0.278	0.278	OK		1			
Q22	2.4597	2.4424	0010	0013	4.3249	0.147	1.230"	0003	0037"	0010	0020	0040	0020	0.210	0.200	0.235	0.209	0.282	0.276	0.280	OK		1			
Q23	2.4594	2.4426	0007	0015	4.3226	0.144	1.231"	0005	0027"	0010	0020	0040	0020	0.210	0.194	0.229	0.208	0.280	0.275	0.274	OK		1			
Q24	2.4616	2.4425	0010	0017	4.3249	0.151	1.229"	0007	0040"	0020	0030	0040	0020	0.208	0.187	0.221	0.206	0.268	0.263	0.266	OK		1			
Q25	2.4607	2.4428	0008	0020	4.3250	0.149	1.229"	0009	0055"	0020	0030	0040	0020	0.207	0.192	0.227	0.206	0.279	0.274	0.278	OK		1		NOT SHIPPED	
Q26	2.4588	2.4422	0010	0014	4.3225	0.145	1.230"	0006	0033"	0020	0020	0040	0020	0.210	0.194	0.233	0.205	0.269	0.262	0.265	OK		1			
Q27	2.4583	2.4431	0009	0017	4.3218	0.144	1.229"	0006	0042"	0010	0030	0040	0020	0.210	0.198	0.236	0.204	0.279	0.274	0.277	OK		1			
Q28	2.4598	2.4432	0010	0020	4.3238	0.146	1.230"	0008	0040"	0020	0020	0040	0010	0.210	0.193	0.240	0.203	0.270	0.265	0.268	OK		1

DETAIL C
SCALE 10/1

Figure B-6
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FIGURE B-7
TRANSIT THERMAL VERIFICATION CAPSULE
ASSEMBLY CLEARANCE DATA