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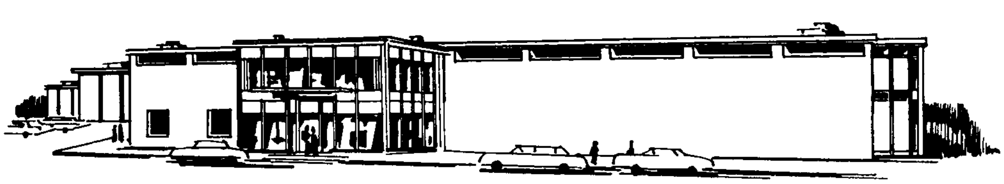

PUTTING TOMORROW'S MATERIALS TO WORK TODAY

C. T. SCHJELDAHL COMPANY
Northfield, Minnesota

FINAL REPORT

FOR

CONTRACT NO. NAS5-9689

(October 21, 1966 - February 1, 1967)

Submitted to:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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ABSTRACT

A manufacturing procedure has been developed for one breadboard model and one prototype model of an instrument to measure the solar constant. This instrument is described in contract NAS5-9689 in accordance with the attached exhibit "A". The solar constant measuring instrument is a thermal housing that surrounds the Blackbody Temperature Sensor. This housing provides a temperature-stable environment for the Blackbody Sensor. The housing is composed of a heater housing, cool aperture, two thermal housings, and base. Each component is equipped with a special thermal coating designed to stabilize temperature. After the construction and design study of the breadboard model was made, one prototype was manufactured by the described process.

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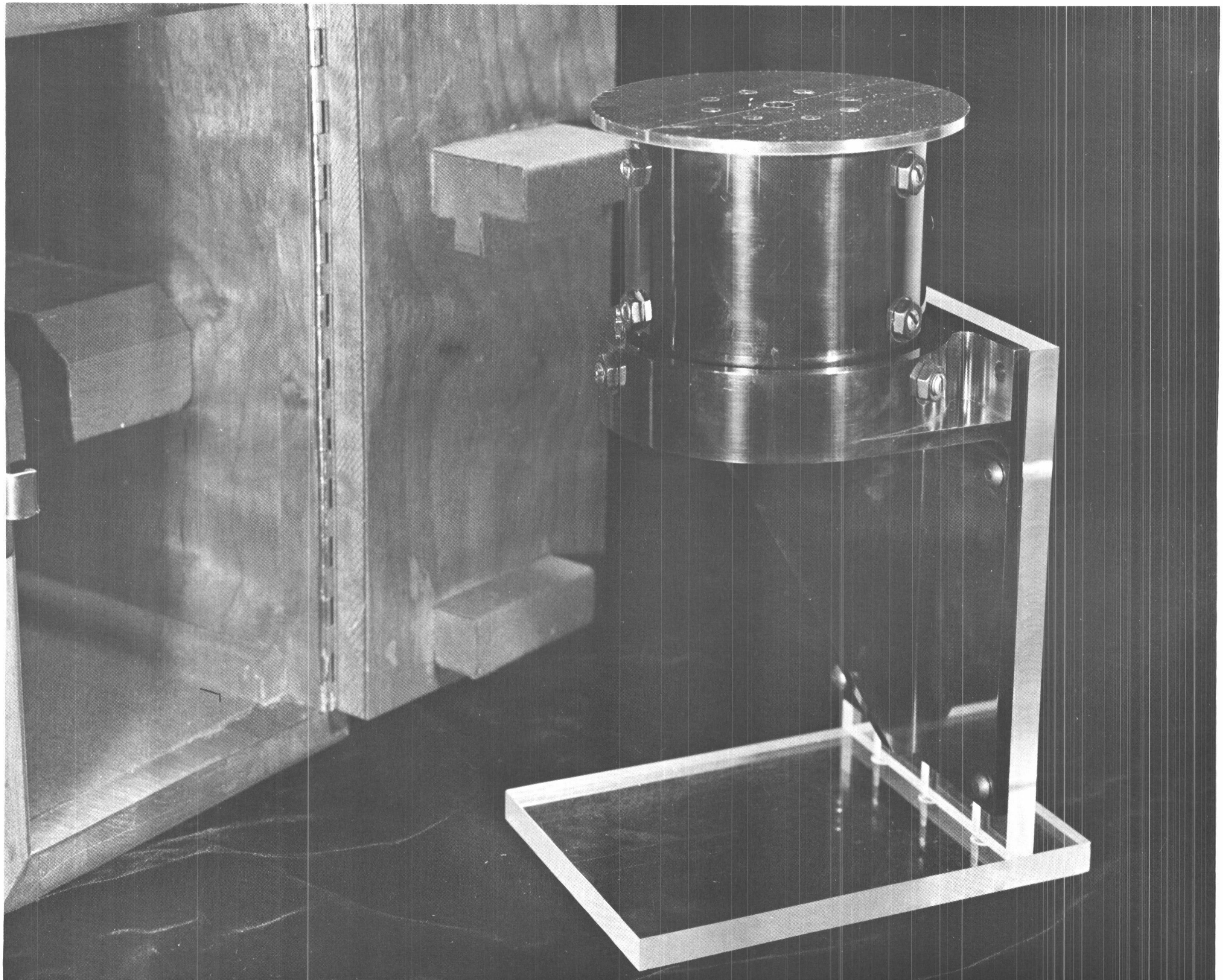

Figure 1 Solar Constant Instrument

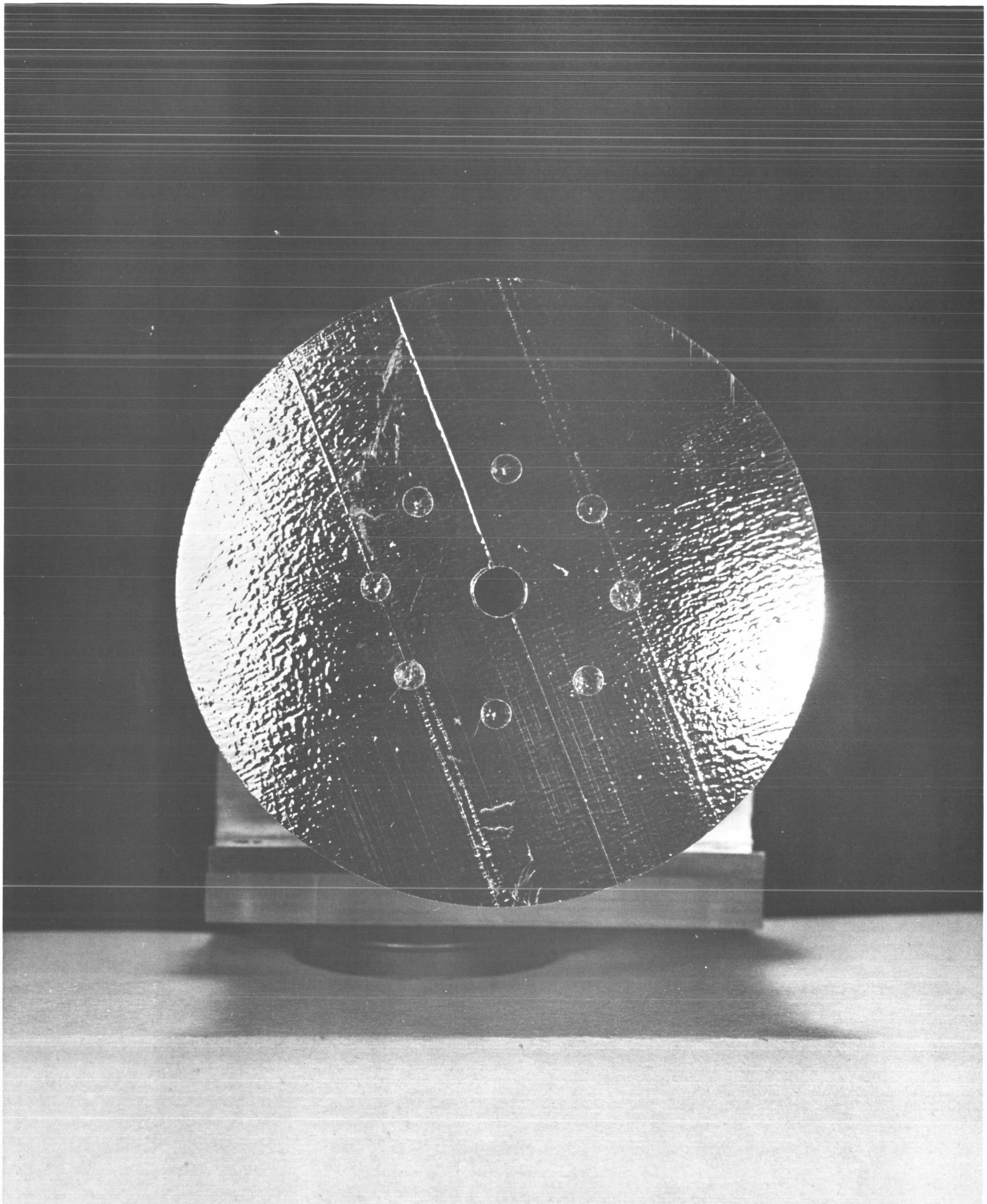

Figure 2 Front Surface with Opening

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LIST OF DRAWINGS (Concd.)

1.0 INTRODUCTION

One (1) breadboard model of an instrument to measure the solar constant was fabricated in accordance with Goddard Space Flight Center Specification entitled "Specification for the Solar Constant Instrument", dated April 27, 1965, except for the following corrections:

A. The resistance of the temperature sensors in the instrument is to be capable of measurements using an alternating current bridge operated at approximately 400 cycles per second.

B. Paragraph 2.1.1 and 3.1.1 is changed to read:

The sensing element is to be reference grade platinum thermometer grade wire.

C. Paragraph 3.4 is changed to read:

The inner surface of the aperture cavity (GSFC Drawings Nos. MB-1886 and MC-1887) is to be coated with a material having an emittance of at least 0.97.

D. Paragraph 2.5.2 the maximum power (heat) loss from the thermostated housing to the instrument casing under operating conditions is 0.33 watts including conductive and radioactive transfer.

Also included with the above GSFC Specification is GSFC technical note D-674, dated April, 1961; Drawing No. LP-1988, dated May 10, 1965, with a list of drawings numbered 1 through 42; and four drawings prepared by G. T. Schjeldahl Company, Nos. 2000196, 2000197, 2000198, and 2000199.

After a feasibility demonstration with the breadboard model, one prototype instrument for possible space flight use was delivered. This unit incorporated many of the design improvements and specification changes requested as a result of the breadboard feasibility study.

1.1 CONFIGURATION

The solar instrument is made up of the following major component parts: The Blackbody Temperature Sensor, the Thermostated Housing with platinum resistance thermometer and heater, a Cool Aperture with platinum resistance thermometer, and a Casing with exterior mounting frame. The assembly weighs approximately 7-1/2 pounds, and is 10-1/2 inches high and 5-1/2 inches square.

1.1.1 The Blackbody Temperature Sensor is a hollow spherical shell, 1.500 ± 0.003 inches in diameter. The surface of the shell contains a platinum resistance winding of 900 ± 100 ohms which senses temperature change transmitted by the inner surface of the sensor. This inner surface is coated with platinum black, with an absorptance (A) of 0.97 and emittance (E) of 0.99 as measured at the Schjeldahl Company. The outside surface of the sensor is coated with vacuum-deposited gold. The sensor is suspended in a network of 3-mil fiberglass which is attached to a mounting ring.

1.1.2 The Thermostated Housing surrounds the blackbody temperature sensor and thermally isolates it from other parts of the instrument. The housing is made in two halves, each half having a hemispherical cavity facing the ball when mounted in position. The two halves when joined together also contain a platinum resistance thermometer and a heater winding. The thermometer resistance is equal to that of the ball within one ohm at 300 K. The heater winding resistance is 240 ± 10 ohms at 420 K. Both the platinum thermometer and the heater windings are coated with 3M Scotch Weld EC 2216 A/B[1], epoxy filler. This material insulates the

[1] Minnesota Mining and Manufacturing Co., St. Paul Minnesota

respective windings and serves as an outer surface which is coated with vacuum-deposited gold.

1.1.3 The Cool Aperture is a hollow cavity mounted directly above the heater housing and limits the field of view of the Blackbody Temperature Sensor. The cool aperture also contains a platinum resistance thermometer wound into its outer surface for the purpose of measuring its temperature. This reference grade thermometer wire resistance is 1400 ± 20 ohms at 300 K. The outer surface of the cool aperture is gold-plated for high reflectance and low emittance for radiation interference from the 420 K blackbody. The inner surface of the cool aperture is cooled with platinum black[1] to absorb all wide angle radiation entering the front opening before it reaches the blackbody sensing area. The front surface is constructed as a plane large enough to hide the entire instrument in its shadow and allows only 90 degree radiation to enter the blackbody sensing area. This surface is coated with aluminum protected with silicon oxide and forms a thermal balance coating.

1.1.4 The Casing is composed of three main parts: the inner casing, the outer casing, and the mounting bracket. The inner casing suspends the heater housing and cool aperture within its walls on a steel ball suspension system. The outer casing holds the inner casing suspended in the same manner. The mounting bracket is mounted at the base of the outer casing in a similar manner. (See DWG 2000805). All three units are 24-K gold-plated over their entire exterior surface to reduce heat transmission between the heater housing and all exterior mounting surfaces. The assembly is not to transmit more than 0.33 watts of power to any exterior mount.

[1] U.S. Naval Radiological Research Laboratory, San Francisco, California

2.0 SUMMARY

Two solar constant instruments were manufactured to meet the intent specified in NAS5-9689. The first instrument or breadboard model was constructed according to GSFC assembly drawing No. LP-1988, dated May 10, 1965, with a list of drawings numbered 1 through 42, and four drawings prepared by G. T. Schjeldahl Company, Nos. 2000196, 2000197, 2000198, and 2000199. The first instrument was delivered May 5, 1966. As this was a breadboard, or primarily a test model, a request to make minor changes in its construction was made by the NASA Project Engineer. The unit was altered and returned on November 3, 1966.

The second instrument, or prototype model, was constructed after a test and evaluation program on the first instrument was completed. A new requirement introduced during this evaluation program was to include a paragraph 2.5.2 as follows: "the maximum power (heat) loss from the thermostated housing to the instrument casing under operating conditions is 0.33 watts including conductive and radiative transfer". This requirement brought about several design changes such as:

The exclusion of the casing release mechanism.

The addition of an extra outer case and the separation of the mounting bracket from the casing.

Gold plating all aluminum parts to reduce heat transmission.

The manufacturing procedure consists of the construction of the following parts:

1.	Bottom cylinder	GTS	DWG	No. 2000809
2.	Top cylinder	"	"	No. 2000810
3.	Aperture Base	"	"	No. 2000811

4.	Aperture cylinder	GTS	DWG	No. 2000812
5.	Sunshield	"	"	No. 2000808
6.	Casing	"	"	No. 2000813
7.	Case	"	"	No. 2000807
8.	Mounting Bracket	"	"	No. 2000806

2.1 THE BOTTOM CYLINDER

The bottom cylinder is a hemispherical cavity in which the blackbody sensor mounting ring is placed. It contains one half of the heater winding and one half of the thermometer winding which matches the blackbody temperature sensor. Its inner surface is coated with electroplated gold and its outer surface is coated with vacuum-deposited gold. The heater and the thermometer windings are wound into grooves in the outer surface, these grooves are filled with epoxy before gold plating.

2.2 THE TOP CYLINDER

The top cylinder is also a hemispherical cavity which fits over the top portion of the blackbody sensor and mates with the bottom cylinder in the center. It contains the other half of the heater and thermometer windings. This unit has an opening at the vertex through which radiation is allowed to pass into the blackbody sensor. This unit is grooved, filled with epoxy, and gold-plated in the same manner as the bottom cylinder.

2.3 APERTURE BASE

The aperture base is affixed to the bottom end of the cool aperture with eight (0-80) screws. It has an opening in the center equal to one square centimeter area. The inside surface is coated with platinum black and its outside surface gold.

2.4 APERTURE CYLINDER

The aperture cylinder is grooved on the outer surface and insulated to receive a 1400-ohm thermometer winding. The thermometer winding is covered with epoxy as were the upper and lower hemispherical cavities. The inside surface is coated with platinum black and the outer surface with vacuum-deposited gold.

2.5 SUNSHIELD

The sunshield or front face of the unit is coated with aluminum and silicon oxide for high reflectance from the sun source. This shield shadows all of the various parts of the instrument except the blackbody aperture. An opening at the center permits radiation to enter the sensing area. Its inside rim is coated with electroplated gold. It is fastened to the top of the cool aperture to enclose the aperture. The surface facing the cool aperture is coated with platinum black.

2.6 CASING

The casing supports the upper and lower hemispherical cavities, and the cool aperture with all its parts. The casing has electroplated gold over its surfaces to reduce heat transmittance between inner and outer parts. Tungsten carbide screws mounted in the wall of the casing provide exact positioning for interior mounted parts.

2.7 CASE

The case is constructed similarly to the casing. It surrounds the inner casing and provides adjustable screws of tungsten carbide, which may be adjusted to position the inner casing. It has electroplated gold over its outer surface to reduce heat transmission as do all adjacent parts.

2.8 MOUNTING BRACKET

This is an L-shaped bracket machined from one solid block of aluminum. This reduces the danger of weldment failure or assembly breakdown during vibrations testing. The bracket is coated with electroplated gold and also provides tungsten carbide mounting hardware that mates with the case.

3.0 DEVELOPMENT OF MANUFACTURING PROCEDURE

3.1 BOTTOM CYLINDER (Drawing No. GTS 2000809)

The bottom cylinder is first machined from a solid bar of 6061-T6 aluminum. It is then electroplated with about 0.0002 of 24-K gold. It is then baked in an oven at 180 C to check the gold adhesion to the aluminum. After passing this requirement, the grooves on the outer surface are brush-coated with 3M epoxy[1]. This epoxy provides an initial insulating coat on which the heater and thermometer is wound. The heater coil is made of Cupron Wire[2] and wound to a resistance of approximately 140 ohms. The thermometer is wound to a resistance of about 450 ohms. The thermometer wire is Sigmond Cohn[3] reference-grade, platinum 99.999 pure. Both windings are terminated at Teflon-insulated terminals[4]. As a final insulating process, the grooves are filled with epoxy over the wires and all excess epoxy removed by machining the outer surface. The outside surface of the epoxy is coated with vacuum-deposited 24-K gold.

3.2 TOP CYLINDER (Drawing No. GTS 2000810)

The top cylinder is constructed in the same manner as the bottom cylinder using the same materials. The top cylinder heater is wound until the combined value of the top and bottom heaters equals 240 ohms. The thermometer is wound so that when it is joined to the bottom cylinder the value is equal to the value of the blackbody to be mounted within the assembly to $\pm$ 1 ohm at 300 Kelvin.

3.3 COOL APERTURE (Drawings No. GTS 2000811, 2000812, 2000808)

The cool aperture is composed of three parts: the aperture base,

---

1. Minnesota Mining and Manufacturing Co., St. Paul, Minnesota
2. Wilbur B. Driver Co., Newark, N.J.
3. Sigmond Cohn Corp., Mount Vernon, N.Y.
4. Sealectro Corp., Mamaroneck, N.Y.

aperture cylinder, and the sunshield. When these three parts are assembled, they form a cavity through which radiation passes on its way to the black-body sensing area. At both ends of this assembly there are openings to let the radiation pass. The bottom opening closest to the sensor is one square centimeter in area, the top is somewhat larger to permit 3 degree angular radiation to enter. The inside surface is coated with platinum black which absorbs all wide angle radiation that may enter the top opening. The Aperture Base is made of 6061-T6 aluminum and is mounted to the aperture cylinder with eight (0-80) screws. The outside surface of the base is coated with vacuum-deposited gold.

The Aperture Cylinder is grooved on the outside for the 1400-ohm thermometer winding. The thermometer is wound in the same manner as the top and bottom cylinder, with epoxy insulation under and over the winding. The Sunshield or top plate is coated with a thermobalance combination of aluminum and silicone oxide. This plate is made of 6061-T6 aluminum and is electroplated with gold on the inside of the rim.

3.4 THE CASING (Drawing No. GTS 2000813)

The casing is machined from 6061-T6 aluminum, polished and electroplated with 24-K gold. This part is placed in an oven at 180 C to test the gold adhesion before assembly is made.

3.5 THE CASE (Drawing No. GTS 2000307)

The case is machined and constructed in the same manner as the casing.

3.6 THE MOUNTING BRACKET (Drawing No. GTS 2000806)

This part is machined from a solid block of 6061-T6 polished aluminum electroplated with 24-K gold. It is also checked in an oven at 180 C for good gold adhesion.

4.0 TEST AND EVALUATION

4.1 THE THERMOMETER SECTIONS

The four main sections of the instrument were temperature cycled to check thermometer stability as well as construction stability in the early stages of assembly. The three aluminum parts, the cool aperture, the upper cylinder, and the lower cylinder had electrical shorts after temperature cycling. These three units were reconstructed using 3M epoxy in place of Pyre ML[(1)] as an insulation barrier under the platinum wire. The units were recycled to 180 C and found to be good.

The Blackbody Sensors were cycled in an oil bath between 160 C and room temperature of 25 C, and found to have a stability of better than 0.02 ohms. The Blackbody Sensors were constructed from a manufacturing procedure developed by G. T. Schjeldahl Company under NASA Contract NAS5-3684, dated 6 February 1964 to 22 April 1965.

4.2 THE MOUNTING SECTIONS

The components were originally held in place by a combination of tungsten-carbide seats, and sapphire balls. One of the carbide seats was held in tension by a mechanical solenoid system. It was found that to apply enough pressure on the balls to sustain instrument rigidity during vibration testing, the ball material had to be changed to stainless steel. Sapphire shattered under the pressure. The mechanical solenoid system was also eliminated.

The instrument components are now mounted with stainless steel balls under tension. (Assembly drawing No. GTS 2000805). This drawing shows the mounted position.

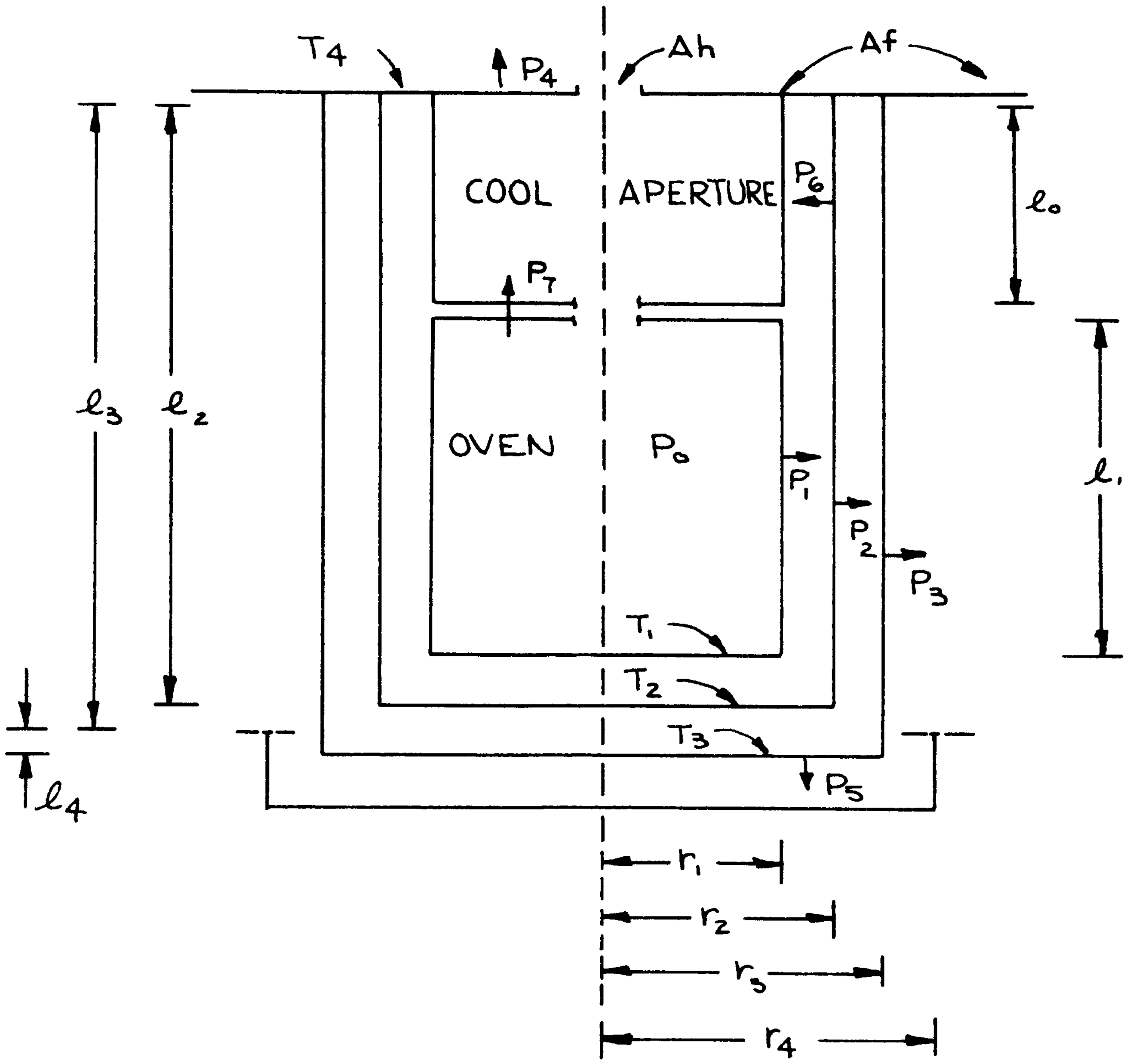
(1) du Pont RK-692 Insulating varnish

SUMMARY

It is assumed that the canister has no infrared energy impinging on it and that its base is held at absolute zero. Conduction losses due to stainless steel ball supports and to electrical leads are neglected. Under these assumptions, heat loss from the canister, except for that occurring from its front surface, is computed to be 0.155 watts.

5.0 TECHNICAL DISCUSSION

The gold ball canister design is illustrated below, exclusive of stainless steel ball spacers and electrical leads.



Sunlight impinges on the upper surface where a fraction α is absorbed except for that sunlight which enters A_h. Effectively α = 1.0 on this hole. The device is taken to have no infrared radiation impinging on it, i.e., the canister is thought of as residing in a large vacuum chamber, chamber wall temperature being at absolute zero. Infrared energy leaves the canister via its front and sides. The only conductive heat loss from the system illustrated above takes place from the bottommost surface of the canister, which is thought of as having its temperature held at absolute zero. The oven is held at 420 K. All surfaces are gold covered, except for the upper surface which has an α of about 0.15 and a thermal emittance ε of about 0.6. The thermal emittance of the gold εg will be taken as 0.025. A "P" in the preceding diagram represents the net rate of energy transfer between the surfaces. Here P_o represents the rate of electrical power dissipation in the oven, and P_4 represents the net rate of energy leaving the cool aperture.

One desires $P_3 + P_5$ to be less than 0.3 watt. To see whether this is true, one begins by writing relationships between the P's.

$$P_6 + P_7 = P_4$$

$$P_1 = P_2 + P_6$$

$$P_2 = P_3 + P_5$$

Now:

$$P_1 = (\pi\ r_1 2 + 2\ \pi\ r_1 \ell_1)\ \frac{\varepsilon_g}{2}\ \sigma\ (T_1^{\ 4} - T_2^{\ 4})$$

$$P_2 = (\pi\ r_2^{\ 2} + 2\ \pi\ r_2\ \ell_2)\ \frac{\varepsilon_g}{2}\ \sigma\ (T_2^{\ 4} - T_3^{\ 4})$$

$$P_3 = 2 \pi r_3 \ell_3 \varepsilon_g \sigma T_3^4$$

$$P_4 = (A_f - A_h) \varepsilon \sigma T_4^4 + A_h \sigma T_4^4 - S_c \alpha (A_f - A_h) - S_c A_h$$

$$P_5 = (2 \pi r_3 \ell_4 + \pi r_3^2) \frac{\varepsilon_g}{2} \sigma T_3^4$$

$$P_6 = 2 \pi r_1 \ell_o \frac{\varepsilon_g}{2} \sigma (T_2^4 - T_4^4)$$

$$P_7 = (\pi r_1^2 - A_h) \frac{\varepsilon_g}{2} \sigma (T_1^4 - T_4^4)$$

Also:

$r_1 = 3.18$ cm

$r_2 = 4.20$ cm

$r_3 = 5.55$ cm

$r_4 = 6.35$ cm

$\ell_o = 2.94$ cm

$\ell_1 = 4.57$ cm

$\ell_2 = 8.56$ cm

$\ell_3 = 7.45$ cm

$\ell_4 = 2.06$ cm

$A_h = 1.0$ cm^2

$S_c/\sigma = (396\ K)^4$

$\alpha = 0.15$

$\varepsilon = 0.6$

$\varepsilon_g = 0.025$

$A_f = 176 \text{ cm}^2$

$\sigma = 5.672 \times 10^{-5} \dfrac{\text{ergs}}{\text{sec-cm}^2\ {}^{\circ}\text{K}^4}$

Consequently:

$$P_1 = \pi\ \varepsilon_g\ \sigma\ 19.6\ (T_1^{\ 4} - T_2^{\ 4})$$

$$P_2 = \pi\ \varepsilon_g\ \sigma\ 44.8\ (T_2^{\ 4} - T_3^{\ 4})$$

$$P_3 = \pi\ \varepsilon_g\ \sigma\ 82.7\ T_3^{\ 4}$$

$$P_4 = \pi\ \varepsilon_g\ \sigma\ \left[1352\ T_4^{\ 4} - (396)^4\ 346.7\right]$$

$$P_5 = \pi\ \varepsilon_g\ \sigma\ 26.8\ T_3^{\ 4}$$

$$P_6 = \pi\ \varepsilon_g\ \sigma\ 9.35\ (T_2^{\ 4} - T_4^{\ 4})$$

$$P_7 = \pi\ \varepsilon_g\ \sigma\ 4.89\ (T_1^{\ 4} - T_4^{\ 4})$$

Substituting the latter expressions for the P's into the previous equations relating the P's gives:

$$9.35\ T_2^{\ 4} + \sigma\ T_3^{\ 4} - 1366\ T_4^{\ 4} = -8.54 \times 10^{12}$$

$$-73.75\ T_2^{\ 4} + 44.8\ T_3^{\ 4} + 9.35\ T_4^{\ 4} = -.61 \times 10^{12}$$

$$44.8\ T_2^{\ 4} - 154.3\ T_3^{\ 4} + \sigma\ T_4^{\ 4} = 0$$

Solving these equations for the unknowns gives:

$T_2^{\ 4} = 324$ K

$T_3^{\ 4} = 238$ K

$T_4^{\ 4} = 282$ K

Heat loss from the canister is given by $P_3 + P_5$. Since this equals P_2 by previous equations, we need compute only P_2.

$$P_2 = \pi \, \varepsilon_g \, \sigma \, 44.8 \, (T_2^4 - T_3^4)$$

$$= .155 \text{ watts}$$

6.0 ELECTRICAL LEADS FOR THE GOLD BALL CANISTER SYSTEM

6.1 SUMMARY

The best method to date for making electrical contact to the innards of the gold ball canister system appears to be to use wire having very nearly zero temperature coefficient of resistance. The diameter of the wire is chosen to keep conductive heat transfer between the canister innards and the canister's external environment low. The net results is that a "constant" resistance is added to the resistance of each of the three platinum resistance thermometers in the gold ball system.

An example using data obtained from the Wilbur B. Driver Company on their copper-nickel alloy wire is worked through. Since chromium is not allowed in the system, conventional resistance wire like, say, Karma (Driver-Harris) cannot be used. The results say that five-or-six-mil-diameter wire should be used from the support to the outer housing while 20-mil-diameter wire should be used elsewhere. A firm conclusion on the performance of this wire must await data on its resistivity over a wider temperature range than is available now. Also, the question of diffusion of the copper-nickel alloy into the platinum must still be considered, as well as what solder one can use to join it to the platinum. It appears that the "constant" resistance which would be added to the ball's resistance would be about 1.6 ohms.

6.2 TECHNICAL DISCUSSION

The theoretical model of the gold ball canister system used in the calculations below is described in a memorandum dated June 17, 1966. There the oven as well as ball temperature is 420 K; the inner housing temperature T_2 is 324 K; the outer housing temperature T_3 is 238 K; the support temperature is 0 K; the cool aperture temperature T_4 is 282 K.

Eight lead wires, each 0.875 inches long, run between the outer housing and the support. We arbitrarily specify that 0.005 watt of power is the maximum conduction allowed through each lead. This gives a total lead wire conductive heat leak of 0.04 watt. To prevent this heat leak from lowering the temperature of the outer housing, we require that the lead wire heat leak between the inner housing and the outer housing also be fixed at 0.04 watts.

There are eight lead wires, each 2.66 inches long, connecting the inner housing to the outer housing. In a similar manner we require that the net transfer of heat from the oven-cool aperture combination to the inner housing be 0.04 watts. Here two leads, each 0.94 inches long, run between the cool aperture and the inner housing; two leads, each 2 inches long (coming from the gold ball) run from the middle of the oven cylinder to the inner housing; four leads, each 3 inches long, run from the bottom of the oven cylinder to the inner housing. Two of the latter leads connect to the heater in the oven; the other two connect to the platinum resistance thermometer in the oven.

Specifications received from the Wilbur B. Driver Company on their copper-nickel alloy wire are:

1. Temperature coefficient of resistance (25 C - 100 C) equals 20×10^{-6} ohm/ohm - ^{o}K
2. Resistivity ρ (20 C) equals 48.9×10^{-6} ohm-cm.

3. Thermal conductivity equals 0.51 cal-cm/cm^2 - sec - $^\circ$K

4. Thermal emf versus platinum 27 (0 - 100 C) equals -0.056 mv/$^\circ$K

The variation in these specifications with temperature is not known so they will be assumed invariant in the computation which follows.

Consider heat loss down the eight 0.875-inch long leads first. The temperature differential across the leads is 238 K. Define the following quantities.

$\overset{o}{Q}$ = heat leak down a lead, watts

K = thermal conductivity of lead, $\frac{\text{cal-cm}}{\text{cm}^2\text{-sec-}^\circ\text{K}}$

A = cross sectional area of lead, cm^2

ΔT = temperature differential across lead, $^\circ$C

D = lead diameter, mils

L = lead length, cm

Now:

$$\overset{o}{Q} = 4.18 \frac{KA\Delta T}{L}$$

Here: $\overset{o}{Q}$ = .005 watt

K = .051 cal-cm/cm^2 - $^\circ$-sec

ΔT = 238 C

L = 2.22 cm

Solving for A gives A = 2.18×10^{-4} cm^2

This makes D = 6.57 mils

Consider heat loss down the eight 2.66-inch long leads. The temperature differential across these leads is 324 - 238 = 86 C.

Here: $\overset{o}{Q}$ = .005 watt

K = .051 cal-cm/cm^2-$^\circ$C-sec

T = 86C

L = 6.75 cm

Solving for A gives $A = 18.4 \times 10^{-4}\ cm^2$. This makes D = 19.0 mils.

Consider the net rate heat transfers to the inner housing from the cool aperture-oven combination via the various leads running between them. Here:

$\overset{o}{Q}$ = total net heat transfer by all leads to the inner housing = .04 watt

ΔT_1 = absolute value of temperature difference between inner housing and cool aperture = 324 - 282 = 42 C

ΔT_2 = difference in temperature between the oven and the inner housing = 96 C

L_1 = length of leads between inner housing and the cool aperture = 2.38

n_1 = number of leads between inner housing and the cool aperture = 2.0

L_2 = length of leads between middle of oven and the inner housing = 5.08 cm

n_2 = number of leads between middle of oven and the inner housing = 2.0

L_3 = length of leads between bottom of oven and the inner housing = 7.62 cm

n_3 = number of leads between bottom of oven and the inner housing = 4.0

The cross sectional area A of the lead wire is found from the following equation:

$$\overset{o}{Q} = 4.18\ KA \left[-n_1 \frac{\Delta T_1}{L_1} + \frac{n_2 \Delta T_2}{L_2} + \frac{n_3 \Delta T_2}{L_3} \right]$$

Substituting numerical quantities into the expression for A gives: $A = 35.4 \times 10^{-4}\ cm^2$. This makes D = 26.4 mils. It is probably best to neglect the negative term in the expression for $\overset{o}{Q}$ above when solving for A, in which case $A = 21.2 \times 10^{-4}\ cm^2$. This makes D = 20.5 mils. In what follows, we use the latter result rather than the former.

The question dealt with next is what the introduction of the leads considered above does to the calibration of the various platinum resistance thermometers. Consider just those two leads attached to the gold ball. Each lead consists of one piece 2.22-cm long having a A = 2.18×10^{-4} cm^2; one piece 6.75-cm long having a A = 18.4×10^{-4} cm^2; one piece 5.08-cm long having a A = 21.2×10^{-4} cm^2. Since the resistivity ρ of the wire alloy is 48.9×10^{-6} ohm-cm, the total resistance R of the two leads is:

$$R = 2\rho \sum_n \frac{L_n}{A_n}$$

$$= 1.59 \text{ ohms } (20 \text{ C})$$

Now the temperature coefficient of resistance of the alloy between 25 C and 100 C is given as 20×10^{-6} $\frac{\text{ohm}}{\text{ohm-}^{\circ}\text{C}}$

If this same temperature coefficient were to apply over the range of 0 K to 450 K, no trouble would be expected as far as changes in the lead resistance destroying the calibration of the platinum resistance thermometer wound on the ball. This can be shown as follows. Since the temperature coefficient is so low, one can just as well take 1.59 ohms as the resistance of the lead wire at 0 C. Then:

$$R = 1.59\,(1 + 20 \times 10^{-6}\,T)$$

Here T is in $^{\circ}$C. If T were -273 C, i.e., 0 K, then

$$R = 1.59\left[1 - 20 \times 10^{-6}\,(273)\right]$$

If T were 177 C, i.e., 450 K, then $R = 1.59\left[1 + 20 \times 10^{-6}\,(177)\right]$.

The change in R between 0 K and 450 K would then be $(1.59)(20 \times 10^{-6})(450)$ = .0143 ohms.

The change which one can tolerate in the platinum resistance thermometer is given by that resistance change in the ball which corresponds to 0.01 C. This change is about 0.04 ohms, which is three times larger than the change computed above. An experimental determination of the resistivity of the alloy over a wide range in temperature would have to be made before a firm conclusion could be drawn, however.

7.0 RESISTANCE VERSUS TEMPERATURE OF CUPRON WIRE

7.1 SUMMARY

The resistance versus temperature characteristics of Cupron wire allow the wire to be used for making electrical connections in the gold ball canister system.

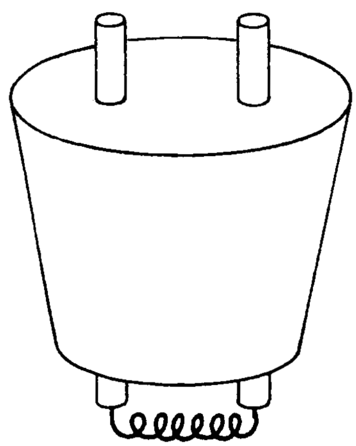
7.2 TECHNICAL DISCUSSION:

The 40-ohm spiral of Cupron wire was stretched slightly to separate the turns and its ends soldered to No. 12 copper wire leads. The copper leads were estimated to have 0.006 ohm resistance at room temperature, the major portion of each lead remaining at room temperature throughout the tests described below.

The Cupron wire considered here was manufactured by the Wilbur B. Driver Company, Newark, New Jersey. The label specifications were as follows:

Size	.0063
Insp.	B
Gross	2.85
Melt	318234
Tare	65
Net	2.20
OD	050

The copper leads were pushed through holes in a large cork as illustrated below.



The resistance coil was immersed in solutions at various temperatures, the following coil resistance readings being obtained.

Solution	Temp C	Resistance
Air	20	40.43
Liquid nitrogen	-196	39.82
Dry ice - acetone	-78	40.39
Oil	165	40.38
Liquid nitrogen	-196	39.82
Oil	+162	40.38
Air	20	40.43

A change of 40.43-39.82 = 0.61 ohms was obtained between room temperature and liquid nitrogen temperature. The memorandum of August 3, 1966 considers a 1.6 ohm resistance and states that a $\pm$ 0.04 ohm change can be tolerated in this resistance from -200 to 200 C. On the basis of data above, an upper bound on the change in resistance with temperature of Cupron wire from -195 C to 160 C is $\frac{1.6}{40} \times 0.61 = 0.024$ ohm. Consequently, it appears that Cupron will be adequate for canister electrical connections as regards its resistance versus temperature properties.