Communications Research Centre

OUTGASSING STUDIES OF POLYMERS FOR SPACECRAFT APPLICATIONS

by

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ABSTRACT

This report describes work carried out on the outgassing properties of proposed spacecraft materials as part of the Communications Technology Satellite (CTS) Project. The rationale for the tests is stated, and equipment design and experimental methods are described. Results of tests carried out on specific materials are given for each class of material, categorized as to type or use. The relevance of the results to CTS experience is briefly discussed.

1. INTRODUCTION

The thermal-vacuum properties - particularly outgassing - of materials used in spacecraft construction are important because of the possibility of volatile components being released in vacuum. Possible consequences of outgassing are;

- pressure rise within the spacecraft which could contribute to electrical breakdown via arcs and coronas;
- deposition of condensible materials on optical and/or thermal surfaces leading to degradation of optical or thermal properties;
- change of properties of polymeric materials as volatile components are released.

During the development phase of the Communications Technology Satellite (CTS) Project, it became obvious that it would be advantageous to perform some outgassing measurements in-house at CRC. Some outgassing data was available in the literature (see references), but was not comprehensive and did not include all the proposed CTS materials. It was therefore decided to construct suitable facilities for performing outgassing tests on proposed CTS materials. Accordingly, three separate test facilities were set up for the use of the CTS Project and CTS Contractors.

2. FACILITIES

2.1 MATERIALS SCREENING

A useful and widely used criterion for the selection of spacecraft materials is that developed by the Stanford Research Institute (SRI)[1,2] and utilized extensively by (1) (NASA-GSFC)[3,4], and, in slightly modified form, by (2) (ESTEC)[5]. It was found empirically at SRI that virtually all volatile components would be released within 24 hours from a thin section of material (less than 1/16 inch) with totally exposed surface area, when heated at 125°C in a vacuum of 10^{-6} torr. A screening test based on this was developed by SRI[2] wherein small samples of material (100-200 mg) were heated to 125°C for 24 hours at 10^{-6} torr. The total weight loss of the sample and the volatile condensible materials (VCM), were measured as percentages of the original weight. The VCM were defined as the materials collected on a plate maintained at 25°C with the system geometry defined such that all evolved outgassing products impinged upon this cold plate.

A NASA criterion based on this test[2,4] is that "acceptable" materials should suffer less than 1% total weight loss and evolve less than 0.1% VCM when subject to the above specified conditions. This criterion was also adopted for the CTS Venting and Outgassing Specification[6]. It should be noted that this is intended only as a screening test, and that more stringent requirements or supplementary tests (e.g. at different temperatures), could be required on occasion. Also, this test gives a total outgassing, and not an outgassing *rate*. However, most spacecraft materials are not subjected to temperatures as high as 125°C, and the test thus represents a realistic "worst case".

Equipment for this test was designed and constructed at the Communications Research Centre (CRC), and is described in Appendix A, together with the experimental technique. The equipment can be used in several ways, including;

- screening tests as outlined above (125°C);
- screening tests at other temperatures;

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1. National Aeronautics and Space Administration - Goddard Space Flight Center.
2. European Space Technology Center.

- collection of VCM on a suitable plate (e.g. quartz, or NaCl) for subsequent U.V., visible or I.R. spectrometry to identify contaminants or to evaluate their effects on transmission (e.g. through solar cell coverslips).

2.2 OUTGASSING RATES

The screening described above yields a *total* outgassing, but no information on outgassing *rate*. The internal pressure in a spacecraft results from an equilibrium between the venting rate (which can be determined analytically from the designed-in venting provisions), and the outgassing rate of (mainly) polymeric materials within the spacecraft. At low ambient temperatures (25-50°C), it can be shown that some materials outgas continuously for many days[7].

Although it is impracticable to measure outgassing rates for all proposed spacecraft materials, it can be useful for a venting/outgassing analysis to obtain outgassing rates at realistic (operational) ambient temperatures for some specific materials. Polymers known to be present in significant quantities and/or specific materials such as rigid urethane potting foams can be a significant factor in overall spacecraft outgassing[8]. Accordingly, a system was assembled which incorporates a vacuum microbalance and sample heating (described in Appendix B). With this system, continuous measurement of thermal-vacuum weight loss at known ambient temperatures is possible over long periods of time.

2.3 CONTAMINANT IDENTIFICATION VIA MASS SPECTROMETRY

In some cases, identification of evolved contaminants in the gas-phase by mass spectrometry is useful. (A recognized NASA-GSFC Outgassing Specification[9] employs this technique.) A heated sample holder was designed for incorporation into an 'Aerovac' high-vacuum system, equipped with a quadrupole mass-spectrometer, and capable of 10^{-12} torr. Small samples (200 mg) could thus be heated to measured temperatures, and the outgassing products examined with the quadrupole mass spectrometer. The equipment is described in Appendix C.

3. RESULTS

During the CTS project, some 200 standard outgassing tests (24 hours at 10^{-6} torr at 125°C) were performed, including 90 tests at contractors' request. These are tabulated in section 3.1. In addition, several non-standard tests were conducted. These are reported in 3.2.

3.1 STANDARD OUTGASSING TEST

3.1.1 Flexible Foams

Many tests were conducted on open-cell, flexible urethane foams, to establish the suitability of the deployable solar array (DSA) interleaf

material proposed by the contractor (SPAR Aerospace Products). The initial samples tested, Monsanto 1835 (2 lb/ft^3 density) and 3865F (4 lb/ft^3 density), gave a high total-weight loss under the test conditions; and more alarmingly, unacceptable VCM because of the contiguity of the material to the solar cell coverslips (see paragraph 3.2). As a practical solution to high outgassing, preconditioning procedures were sought and tests were made after the following conditioning cycles had been made:

1. Thermal vacuum treatment
2. Methanol washing followed by bake drying
3. Isopropanol washing followed by bake drying
4. Detergent washing followed by bake drying

Of these 1, 2, and 3, were successful in reducing the weight-loss percent, and percentage VCM, to acceptable standards.

It was subsequently discovered that the foam, as supplied to SPAR, contained a fire retardant, which was the major cause of high VCM figures. Further tests conducted on foams without fire retardant gave acceptable VCM figures, without any preconditioning.

It was found that the Total Weight Loss figures were usually greater than 1%, i.e. nominally outside specifications. Moreover, following the thermal-vacuum treatment used in the test, it was shown that the foams regained most of the Weight Loss when exposed to a laboratory atmosphere. It was concluded that most of the 'Total Weight Loss' was due to release of absorbed water vapour, which was replaced, typically in 1-2 days, in a laboratory atmosphere. The reason for the reabsorption is the high porosity of the open-cell foam.

Since the foam was not contained within the main spacecraft body, the high weight loss figures were not a factor in high voltage breakdown: accordingly SPAR issued a revised specification[10], which allowed up to 3% total weight loss for this material alone. The original requirement for VCM (less than 0.1%) was retained.

Samples from each batch of material procured for flight use were tested to ensure compliance with the revised specification.

Table I summarizes results gained on flexible foams. Most tests were conducted on *Monsanto 1835* as proposed by SPAR for D.S.A. packing; the 'Continental' foam was a suggestion made by A.E.G. - Telefunken, the manufacturers of the Deployable Solar Array Blanket.

3.1.2 Rigid Foams

In several instances, rigid closed-cell urethane foams were proposed for electronic packaging. While this is an established packaging technique, there were several special factors in the CTS project, viz:

- weight factors dictated the use of a low-density foam: the goal for some sub-systems was 2 lb/ft^3 (.032 g/cm^3) density;

- at densities below ~6 lb/ft^3 (.096 g/cm^3), urethane foams become increasingly open-celled, hence porous, and the outgassing is likely to increase;

- overall, several pounds of foam were to be used in the spacecraft, making potting foams one of the most important materials from the standpoint of reduction of outgassing products;

- due in part to recent U.S. regulatory action, several promising foams were no longer manufactured, including the material previously used on the 'ISIS' programmes, for which R.C.A. had developed procedures.

Table II is a summary of results obtained on rigid foams; most of these were candidate materials proposed by R.C.A. Of these, *UF3 (Conap), Vultafoam 16F-1402,* and *Uralane 573* were utlimately rejected because of extremely high outgassing figures. In addition to tests carried out at 125°C, other tests were performed at room temperature and 75°C. It is noteworthy that some foams outgassed at measurable rates for long times - typical samples of rejected foams were losing 0.5% weight per day after 6 days at 75°C, and 0.1% per day after 11 days at 25°C.

The foam eventually selected by both CRC (for SHF Beacon electronics) and RCA was *Eccofoam FPH*: it was found that curing at ~60°C reduced Total Weight Loss to a figure which was acceptable, although marginally exceeding the 1% goal.

3.1.3 Adhesives

The selection of *Epiphen ER 825A* as a general adhesive for CTS was made because of its room temperature cure and excellent adhesive properties. Initial outgassing tests, however, showed that the material did not conform to the outgassing goal. Because of its widespread use on CTS, some experiments were performed which were aimed at reducing the outgassing of the cured adhesive. It was found that, by adding a drying cycle of the asbestos and silica fillers used prior to mixing, the outgassing could be brought within the goal of 1% Total Weight Loss. *HYSOL EA934*, another structural adhesive, was also qualified without modification. Of the flexible adhesives, Dow Corning low-volatile content materials, *DC 6-1104* and *DC 6-1109* silicone adhesives, also proved to be completely acceptable.

Table III summarizes the results obtained on adhesives.

3.1.4 Potting/Coating

Table IVa lists outgassing results obtained on potting and coating materials.

Qualification of a suitable material for potting and coating applications was necessary because of the requirement for "in situ" potting of wiring harness Cannon connectors, thermocouple/thermistor terminals, etc.,

and for sundry coating applications. Requirements for these applications include:

- room temperature cure;
- ready availability;
- suitable handling properties (viscosity, ease of formulation);
- mechanical properties when cured (flexibility).

Initially, *Baker Castor Oil System #65* was an obvious choice; it had the appropriate outgassing requirement, room temperature cure, suitable viscosity (pre-cure) and flexibility (post-cure). The materials were, however, withdrawn from the market during the project, and most of the results listed in Table IVa were part of an effort to define a substitute material. *Scotchcast 221* was eventually chosen on the strength of its room temperature cure, combined with in-specification outgassing properties. Modifications of this material were also used on the project, in particular;

- inclusion of various properties (4-8%) of dried "CAB-O-SIL' (silica) filler were used to increase the viscosity suitably for conformal coating or terminal insulation;
- inclusion of SC-72 (Cabot) graphite was used to produce a conductive adhesive for bonding second surface mirrors.

Conductive Potting and Coating - Conductive potting material was also required for potting of pyrotechnic circuit connectors, ground lug installation, and conformal coating of wave guides. The material selected for these application was *Eccobond 57C* (silver-filled). The material was either used as per the manufacturers' specification, or was used with 10% toluene added to improve handling properties during application. The results are listed in Table IVb.

3.1.5 Wiring Harness Materials

Before commencing the assembly of the CTS Engineering Model wiring harness, all major materials and components proposed for use were screened by the standard process. Table V is a summary of results obtained.

The majority of proposed materials, i.e., wire-coating, wire-splices, shrink-tubing, tie-downs, etc., proved to be within the guidelines for space approved materials, however, the 'Ty-raps' and cable clips proposed for use (item 1-3) were not, being above the maximum allowable weight loss of 1.0%. It was assumed that the volatile material in this case was H_2O, since nylon normally has a water content which acts as a plasticiser.

Ultimately, the nylon cable clips were replaced by clips fabricated (at CRC) from G10 epoxy-glass fiber laminate (also tested, see Table V). There were, however, no suitable substitutes for the nylon 'Ty-raps', although Ty-raps made of 'Tefzel' (fluorocarbon) were tested and found to be within specification, these were essentially in development status and could not be obtained in sufficient quantity for CTS use.

3.1.6 Silicone Rubber RTV

RTV 11, a silastic material made by General Electric, was selected as a thermal interface material between CTS panels and mounted units. Many tests were made on the material after various cure times (3-61 days). The results showed that the percentage weight loss and percentage VCM were above the allowable maxima. However, in this application the area of this material which would be exposed to space conditions (a line at each interface approximately .009" thick), the small total volume and the fact that thermal interface tests made with RTV 11 had proved very successful, made the selection advisable.

RTV 566A, a space-grade silastic rubber, also produced by General Electric, was tested and found to be non volatile and therefore space qualified; but high cost, long lead-times and short shelf-life made general use impracticable. The results of these tests are listed in Table VI.

3.1.7 Adhesive Tapes

Adhesive-backed tapes of glass, metal, polymers, or composites thereof, are useful on spacecraft for thermal control coating, RF shielding, electrical insulation and thermal insulation. The adhesive backing may be either acrylic or silicone, and is in most cases the critical factor in the outgassing properties. Tapes were tested adhered back-to-back to simulate applicable conditions, and allowed to cure.

In general, most of the tests were conducted on possible substitutes for the preferred materials, which were plagued by long lead times. Of those listed, 3M's '79' was used extensively: other tapes used were mainly 'Mystic' brand materials, for which extensive test results already existed in NASA literature. Results obtained on adhesive tapes are detailed in Table VII.

3.1.8 Miscellaneous Materials

Many miscellaneous materials were tested during CTS construction, either to qualify proposed materials, or to examine specific materials incorporated into fabricated parts.

A particular example was a fibreglass collar, produced by Leigh Instruments, which was adhered to the spacecraft aft deck, and whose function was to prevent the possibility of a high-voltage breakdown between the 200 watt Travelling Wave Tube and the deck. The outgassing tests established a cure cycle which produced a material having an acceptable outgassing performance.

Many materials were, as previously stated, either qualified or rejected on the results listed in Table VIII.

3.1.9 Paints

The need for a room-temperature-curing low-outgassing paint still exists. High-gloss epoxy paints with a thermal cure cycle are found to be low outgassing, but these are comparatively thick, and therefore create an added weight problem. Consequently a suitable flat black paint which could

be applied in thin layers was sought. Of the paints tested, only *Paladin Inmont* was found to be close to the accepted NASA GSFC standard of 0.1% VCM and 1.0% weight loss. The results of the tests performed are listed in Table IX.

3.2 SPECIAL TESTS

3.2.1 Non Standard Outgassing

In addition to the standard outgassing test results tabulated in paragraph 3.1, several non-standard test results (e.g. long-term, low-temperature thermal-vacuum cycles), are listed. These tests were made to establish a better understanding of the behaviour of polymers under the actual conditions that the material would encounter during flight. In some cases, materials which did not conform to the recommended NASA-GSFC standard of 0.1% VCM and 1.0% weight loss were qualified using revised standards. In particular, this occurred in the case of materials for which there were no substitutes, or whose other properties (e.g. mechanical, electrical, thermal) were satisfactory.

Examples of these include *RTV 11* thermal interface material (para. 3.1.6); DSA foam interleaf material (para. 3.1.1); rigid urethane potting foams (para. 3.1.2).

3.2.2 Spectroscopy

Identification of some of the volatile condensibles by means of IR spectroscopy was undertaken. These materials included contaminants appearing on SHF antenna dishes during thermal/vacuum testing, foreign materials found on the flexible solar array blanket, etc. A monitoring of the CRC David Florida Laboratory vacuum test chambers was also carried out to establish that the test equipment was not contributing to contamination during thermal/vacuum cycling.

UV and visible spectroscopy was used to examine the transmission of solar cell coverslips and possible degradation due to absorption by volatiles condensed from foam interleaf materials. This is extremely critical, because any contamination in this area could lead to an ultimate reduction of power to the spacecraft. Further, it is not known how much more degradation could occur with possible polymerization of the VCM after long periods of exposure to UV during flight.

The samples were collected in the equipment described in Appendix A, with the copper collectors replaced by polished NaCl flats for the IR investigations, and quartz cover glass on the collector for UV and visible light transmission examination.

IR spectra were obtained using a Perkin-Elmer Model 337 spectrometer and, UV/visible spectra with a Cary 14.

3.2.3 Water Absorption

In general, water is the main constituent of outgassing products desorbed from urethane foams, both flexible (used as D.S.A. interleaf material) and rigid (used as potting material).

As noted in paragraph 3.1, the flexible foam D.S.A. interleaf material was eventually used under a revised specification of 3% weight loss, and less than 0.1% VCM. This was necessary because it was shown that after outgassing, water uptake was sufficient to given an outgassing figure of this order, even from a controlled laboratory atmosphere at 40% humidity. Because of the 'open cell' structure of the flexible foams, this was unavoidable.

In the case of the rigid urethane foams described in Paragraph 3.1, water uptake was measured following;

i) immersion in water;

ii) 100% humidity (room temperature);

iii) <40% humidity (room temperature).

The results were used to give an indication of the porosity of candidate materials. This was significant as the rigid foams should be predominantly 'closed cell' in structure, hence of low porosity.

3.2.4 Outgassing of Honeycomb Panels

Following discussion at the Structure Critical Design Review, it was decided to test panel outgassing rates (both aluminum and epoxy-glass fiber face-sheets), using panel samples supplied by SPAR. The aims were:

- To investigate the need for panel conditioning;
- to define, if necessary, optimum conditions for panel conditioning.

The basic problem was the lack of information on spacecraft panel outgassing, hence the need for panel conditioning by thermal vacuum treatment. Furthermore, any conditioning procedure would have been arbitrary unless it was first demonstrated by test.

Outgassing of panel samples was carried out according to a test plan (CRC 666-9-12, dated 22 July, 1974) written by Brown, Naresimhan (SPAR), and Buckingham. Briefly, the tests were as follows:

- Three samples of each type of panel were used, each sample being approximately three inches square.
- Each sample was weighed and subjected to appropriate thermal-vacuum treatment in the DFL three-foot chamber.
- The samples having aluminum face-sheets were subjected to a total of 19 hours at 80°C in vacuum of 10^{-6} torr. At intervals, the vacuum was broken, and the samples were weighed.

- The samples having fiberglass face-sheets were subjected to similar treatment, with an additional Thermal-Vacuum cycle of 24 hours at 125°C.

- The temperatures were chosen so as to be below fabrication temperature, but close to predicted operating temperatures.

- Following thermal-vacuum outgassing, all samples were left in an uncontrolled laboratory atmosphere, and weighed at intervals to measure the uptake of water vapour.

Results are shown in Table X and are summarized as follows:

Aluminum Face-Sheet

- The samples lost about 0.1% weight after a total of 19 hours at 80°C, at 10^{-6} torr.

- This weight was regained in a lab. atmosphere after four days; the weight thereafter fluctuated with laboratory humidity, in some cases rising above the starting weight.

Epoxy-glass-fiber Face-Sheets

- The samples lost about 0.6% weight after a total of 19 hours at 80°C and 10^{-6} torr; and around 0.64% after an additional 24 hours at 125°C.

- Most of the weight was regained in a lab. atmosphere after 3 days, and the weight then fluctuated with lab. humidity. The weight of one sample rose above the starting weight.

- The main conclusions were:

  - The effects of any outgassing process were easily reversed;

  - the total outgassing was relatively low (particularly for aluminum panels).

Since the evidence was that outgassing was mainly caused by desorption of water vapour, which was reversed in a lab. atmosphere, it was recommended that no thermal-vacuum conditioning of Flight panels be performed. The recommendation was accepted.

4. DISCUSSION AND CONCLUSIONS

From our experience on CTS, there is little doubt of the general validity of the NASA-GSFC outgassing criterion as a screening procedure, or of the usefulness of results obtained by testing proposed spacecraft materials according to this criterion.

The initial reason for setting up the equipment was the paucity of data existing at the time (1972). Although more comprehensive outgassing data is now available from NASA sources[4], we still consider it important that such equipment be directly available on a project, for reasons which include;

- formulations change; materials should be rechecked at intervals;
- materials disappear from the market and replacements must be tested;
- outgassing figures depend on pretreatment (curing cycle and/or conditioning): These may be unique to a particular application;
- the equipment is adaptable to other uses - e.g. outgassing at different temperatures or collection of VCM for I.R. spectroscopy (see Paragraph 3.2).

We feel that there is considerable benefit to be gained also from long-term outgassing tests at realistic ambient temperatures - measuring outgassing rates as opposed to *total* outgassing - such as could be performed with the vacuum microbalance or with the mass spectrometer system. In particular, it is advantageous in a venting/outgassing analysis to have foreknowledge of rates of outgassing of commonly used polymers. However, such information could only be obtained over a reasonably long term and possibly in the context of a separate research project.

5. ACKNOWLEDGEMENT

We would like to acknowledge contributions made by Ted Watts in the design and fabrication of the equipment; and by Stephen Ross, who though a budding Theoretical Physicist, made many routine measurements over two summers.

6. REFERENCES

1. Harrington & Maxwell, *Polymers for Spacecraft Hardware: Test Equipment Design*, SRI Project NASA CR-81381, 1966.

2. Muraca and Whitick, *Polymers for Spacecraft Applications*, Stanford Research Institute, SRI Project NASA CR-89557 (National Technical Information Service access No. 67-4070 (1967).

3. Fisher and Mermelstein, *Micro Volatile Condensable Material System for Polymer Outgassing Studies*, G.S.F.S. report number X 735-69-471, October 1969.

4. Campbell, Marriot and Park, *A Compilation of Outgassing Data for Spacecraft Materials*, NASA Technical Note D 7363, September 1973.

5. Dauphin, *Guidelines for Space Materials Selection*, ESTEC specification QRM-01.

6. Brown, A.S., *CTS Venting and Outgassing Specification*, CTS 5.8-114, 1973.

7. Jensen, McCauley, McLouley, and Honma, *Vacuum Thermagravimetric System for Determination of Continuous Weight Loss and Total Condensable Materials*, SAMPLE Conference Proceeding, p. 179, 1972.

8. Dunaetz and Tuckerman, *Selection and Evaluation of Organic Dielectric Materials for Spacecraft*, SAMPLE Journal, p. 23, October/Nov. 1967.

9. *Outgassing, Thermal Vacuum Specification*; NASA-MSFC Specification MSFC 40M51204.

10. SPAR Materials Specification 04-06 Requirements for Polyurethene Flexible Foam Material Open Cell 2 lb/Cu ft. Issue 2, September 1974.

TABLE I

Flexible Foams

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Flexible foam Silicon rubber	2.06	0.46	Standard	R.C.A.	Proposed packaging material (PMC encoder).
2.	Monsanto 5 lb/ft.^{3} 3850 F	3.39	0.79	Standard	SPAR	Proposed D.S.A. interleaf material.
	Monsanto 5 lb/ft.^{3} 3850 F	3.41	0.86	Standard	SPAR	Same as above.
	Monsanto 5 lb/ft.^{3} 3850 F	3.89	0.84	Standard	SPAR	Same as above.
	Monsanto 5 lb/ft.^{3} 3850 F	3.92	0.85	70 hours at standard temperature and pressure.	SPAR	Same as above.
3.	Monsanto 2 lb/ft.^{3} 1835	5.4	0.66	Standard	SPAR	Same as above.
	Monsanto 2 lb/ft.^{3} 1835	5.3	0.56	Standard	SPAR	Same as above.
	Monsanto 2 lb/ft.^{3} 1835	4.05	0.39	Standard	SPAR	Same as above.
	Monsanto 2 lb/ft.^{3} 1835	3.67	0.35	Standard	SPAR	Same as above.
4.	Continental A/NN 2 lb/ft.^{3}	1.04	0.23	Standard	A E G Telefunken	European candidate material.
5.	Monsanto 4 lb/ft.^{3} 3865 F thermal vacuum conditioned	0.43	0.02	Standard	SPAR	Thermal vacuum treatment of 80-100°C for 72 hrs at 10^{-6} torr.
6.	Monsanto 2 lb/ft.^{3} 1835 F Thermal vacuum conditioned	0.85	0.16	Standard	SPAR	Same as above.
7.	Monsanto 4 lb/ft.^{3} 3865 F	0.48	0.02	Standard	SPAR	Conditioning cycles of 1) 24 hrs soak in methanol followed by 1/2 hr in fresh methanol. 2) Dried at 90°C for 16 hrs.
8.	Monsanto 2 lb/ft.^{3} 1835. Methanol washed	0.48	0.02	Standard	SPAR	Same as above

9.	Monsanto 3865 F	3.97	0.35	Standard	SPAR	Collected on quartz for IR/Visible light tests.
10.	Monsanto 4 lb/ft.^{3} 3865 F	3.09 3.07	0.75 0.79	24 hrs at 50°C plus 48 hrs at 80°C	SPAR SPAR	Thermal vacuum conditioning. Thermal vacuum conditioning.
11.	Monsanto 3865 F after thermal treatment (above).	1.4	0.06	Standard	SPAR	
12.	Monsanto 3865F	3.0	0.07	72 hrs at 80°C	SPAR	Thermal vacuum conditioning.
13.	Monsanto 3865 F after thermal vacuum treatment above.	0.8	0.02	Standard	SPAR	
14.	Monsanto 3865 F	0.48	0.02	Standard	SPAR	Methanol washed and baked as in No. 7.
15.	Monsanto 1835	0.7	0.01	Standard	SPAR	Same as above.
16.	Monsanto 1835	3.2 3.2	0.16 0.15	Standard Standard	SPAR SPAR	
17.	Monsanto 1835	0.15	0.054	Standard	SPAR	Cleaned foam (short term clean and bake).
18.	Monsanto 1835	0.38	0.04	Standard	SPAR	Same as above.
19.	Monsanto 1835	0.4	0.05	Standard	SPAR	Same as above.
20.	Monsanto 1835	0.5	0.05	Standard	SPAR	Same as above.
21.	Monsanto 1835	15.0 10.8	1.9 1.8	Standard Standard	SPAR SPAR	Detergent washed. Same as above.
22.	Monsanto 1835	4.6	0.56	Standard	SPAR	With fire retardant.
23.	Monsanto 1835	0.74	0.01	5 1/2 days at 50°C plus 10^{-6} torr	SPAR	

24.	Monsanto 1835	4.8	0.15	Standard	SPAR	
	Monsanto 1835	2.4	0.05	Standard	SPAR	
25.	Monsanto 1835	0.7	0.01	5 days at 50°C and 10^{-6} torr.	SPAR	
26.	Monsanto 1835	0.9	0.017	Standard	SPAR	Sample from flight material batch, SPAR ref. WA36230
	Monsanto 1835	1.2	0.02	Standard	SPAR	Same as above
	Monsanto 1835	1.1	0.016	Standard	SPAR	From roll C.
	Monsanto 1835	0.7	0.05	Standard	SPAR	From roll C.
27.	Monsanto 1835	3.0	0.08	Standard	SPAR	A 46604.
	Monsanto 1835	1.6	0.02	Standard	SPAR	A 46604.

NOTE: All Monsanto samples prior to =24 contained fire retardant.

TABLE II

Rigid Foams

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	EFF-14	1.25	0.083	Standard	D. Buchanan	Cured at 50°C 16 hrs.
	EFF-14	3.0/1.8	0.01	Standard		Cured at 95°C 16 hrs.
2.	UF3 (Conap).	13.0	0.09	Standard	RCA	
	UF3 (Conap).	10.0	0.04	24 hrs at 75°C	RCA	
	UF3 (Conap).	1.5	0.05	Standard	RCA	Cured at 60°C for 16 hours.
3.	FPH 12-4H	1.9	0.05	Standard	CRC	Cured at 60°C for 16 hours.
	FPH 12-4H	2.2	0.06	Standard	CRC	Cured at 60°C for 16 hours.
	FPH 12-4H	2.2	0.02	Standard	CRC	Cured as above using hot mold. (All tests conducted to develop potting method for SHF beacon).
	FPH 12-4H	1.7	0.04	Standard	CRC	Cured for 2- 16 hr. periods at 60°C.
	FPH 12-4H	1.3	0.05	Standard	CRC	Cured for 3- 16 hr. periods at 60°C.
	FPH 12-4H	1.2	0.01	Standard	CRC	Cured for 4- 16 hr. periods at 60°C.
4.	Vultafoam 16F-1402	13.0	0.09	Standard	RCA	
	Uralane 537	12.0	0.01	Standard	RCA	
	Vultafoam 16F-402	2.6	–	24 hrs. at 75°C at 10^{-6} torr	RCA	
	Uralane 573	1.7	–	72 hrs. at room temp. at 10^{-6} torr	RCA	
	Vultafoam 16F-1402	1.5	–	72 hrs. at room temp. at 10^{-6} torr	RCA	
	Uralane 573	4.0	–	24 hrs. at room temp. at 10^{-6} torr	RCA	
	Vultafoam 16F-1402	2.2	–	120 hrs. at 25°C	RCA	
	Uralane 573	1.4	–	120 hrs. at 25°C	RCA	
	Vultafoam 16F-402	2.4	–	120 hrs. at 25°C and 24 hrs. at 70°C.	RCA	
	Uralane 573	1.9	–	Same as above	RCA	

5.	Eccofoam FPH/12/2H	2.1	0	Standard	RCA	Cure cycle 60°C for 8 hrs.
	Eccofoam FPH/12/4H	1.2	0	Standard	RCA	Cure cycle 60°C for 8 hrs.
	Eccofoam FPH/12/2H	4.1	0.16	Standard	RCA	
	Eccofoam FPH/12/2H	3.6	0.07	Standard	CRC	16 hrs. at 60°C cure.
	Eccofoam FPH/12/2H	2.5	0.06	Standard	CRC	16 hrs. at 60°C cure.
	Eccofoam FPH/12/2H	2.9	0.05	Standard	RCA	16 hrs. at 60°C cure.

TABLE III

Adhesives

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Epiphen ER825A	1.8	0.04	Standard	CRC	Structural adhesive cured as specified by manufacturer.
	Epiphen ER825A	3.0	0.07	Standard	CRC	Fillers dried 2 hrs - at 150°C. Cured 67 hrs at room temperature
	Epiphen ER825A	2.0	0.02	Standard	CRC	Filler dried at 150°C for 24 hours. Cured 72 hrs at room temperature.
	Epiphen ER825A filler only	2.3	–	Standard	CRC	
	Epiphen ER825A	1.5	–	Standard	CRC	
	Epiphen ER825A	0.389	0.09	Standard	CRC	Made without filler.
	Epiphen ER825A	0.45	0.01	Standard	CRC	Room temperature cure for 14 days. Fillers dried for 72 hours at 30°C.
	Epiphen ER825A	2.0	0.03	Standard	CRC	Room temperature cure for 9 days.
	Epiphen ER825A	1.48	0.03	Standard	SPAR	SPAR process.
	Epiphen ER825A	1.4	0.03	Standard	SPAR	SPAR process with post cure of 4 hrs at 160°C.
	Epiphen ER825A	0.9	0.02	Standard	SPAR	SPAR process with dried fillers (110°C for 16 hrs. Room temperature cured for 3 days.
	Epiphen ER825A	0.6	0.01	Standard	SPAR	As above.
	Epiphen ER825A	0.6	0.05	Standard	CRC	Batch used on e.m. spacecraft.
2.	EA934 Hysol.	0.27	0.01	Standard	CRC	Structural adhesive.
	EA934 Hysol.	0.15	0.01	Standard	CRC	Structural adhesive.
3.	Crest resin 3135/7111	0.53	0.09	Standard	CRC	Semi-flexible epoxy.
4.	Dow-Corning DC61104	0.12	0.05	Standard	CRC	Low volatile content silicone used extensively on CTS for strapping and heater applications.

5.	Dow-Corning DC61109	0.16	0.033	Standard	CRC	Low volatile content silicone used extensively on CTS for strapping and heater applications.
6.	Hysol 5172	0.31	0.04	Standard	RCA	High temperature adhesive.
7.	Hysol EA901	0.37	0.03	Standard	RCA	High temperature adhesive.
8.	A701 Armstrong	0.27	0.09	Standard	RCA	High temperature adhesive.
9.	Epoxy-patch	0.87	0.069	Standard	CRC	Madex by the Dexter corporation.
10.	Ablestick No. 542	3.0	0.3	Standard	RCA	
11.	Lefkoweld 109/LM52	1.4	0.03	Standard	RCA	
	HT 424 1)	0.88	0.17	Standard	CRC	Cured for 1/2 hr. at 65°C.
	HT 424 2)	0.65	0.16	Standard	CRC	Cured for 2 hrs. at 65°C.
	HT 424 3)	0.18	0.02	Standard	CRC	Cured for 3 hrs. at 65°C.
	FM 123	0.98	0.02	Standard	CRC	Cured for 1 hr. at 121°C. (Structural adhesive film used on CTS.)

TABLE IV a

Urethanes (Flexible Potting and Coating Materials)

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Baker Castor Oil No. 65 System	0.28	0.05	Standard	CRC	Cured according to RCA's spec (no toluene).
	Baker Castor Oil No. 65 System	1.2	0.064	Standard	CRC	Prepared as follows: 1) Resin heated at 60°C – 2 hrs. 2) Outgassed after mixing for 1/4 hour. 3) Outgassed in preheated mold for 1/2 hour. Cure cycle 16 hrs. at 60°C.
	Baker Castor Oil No. 65 System	0.9	0.17	Standard	CRC	Normal treatment and cure.
2.	Emerson Cuming CPC41	0.45	0.09	Standard	CRC	8 day cure at room temperature.
3.	Scotchcast 221	4.0	0.5	Standard	CRC	Sample overheated during test – to be repeated. Room temperature cure.
4.	Scotchcast no. 8	10.5	0.4	Standard	CRC	Connector potting possibility.
5.	Hysol 4183/3165	0.6	0.02	Standard	CRC	Flexible epoxy, RCA suggestion for potting.
6.	Emerson and Cuming Lab. No. 1620.	20.0	1.4	Standard	CRC	Potting possibility.
7.	Scotchcast 221	0.7	0.055	Standard	CRC	Potting possibility.
	Scotchcast 221	1.15	0.05	Standard	CRC	7 day room temperature cure.
	Scotchcast 221	0.53	0.04	Standard	CRC	13 days room temperature cure.
8.	Baker Castor Oil Vorite No. 6	2.1	0.66	Standard	CRC	Cured at 80°C for 16 hrs. Potting possibility.

TABLE IV b

Conductive Potting Material

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Chomeric conductive epoxy	3.5	0.41	Standard	CRC	Material is in a two part bag, mixing is not easily achieved.
2.	Emerson and Cuming Eccobond 57 C without toluene	0.5	0.026	Standard	CRC	
	Eccobond 57 C with 10% toluene	3.0	0.045	Standard	CRC	

TABLE V

Wiring Harness Materials

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Ty-rap (small)	1.55	0.02	Standard	CRC	Small size. Supplied by P. Townsend.
2.	Cable clip	1.60	0.02	Standard	CRC	Small size.
	Cable clip	1.52	0.02	Standard	CRC	Large size. Supplied by P. Townsend.
3.	Ty-rap	1.2	0.02	Standard	CRC	Large size as in item 2.
4.	Thermofit	0.25	0.038	Standard	CRC	Connector
	Thermofit	0.10	0.01	75°C for 24 hrs. at 10^{-6} torr	CRC	Connector
5.	Tefzel ty-rap	0.33	0.01	Standard	CRC	These clips are not available in quantity.
6.	Shrinkable sleeving	0.75	0.15	Standard	CRC	Contingency material (aluminum coated).
	Shrinkable sleeving	0.88	0.18	Standard	CRC	from P. Townsend.
7.	G 10 Epoxy fibreglass laminate	0.64	0.02	Standard	CRC	Used for fabricating cable clips.
8.	Wire splice Thermofit	0.25	0.02	Standard	CRC	20 samples in all. Results averaged. Supplied by P. Townsend.
9.	Chomeric "CHO-SHRINK"	1.1	0.17	Standard	CRC	
	Tubing	0.5	0.04	Standard	CRC	
10.	Teflon coated wire	0.14	0.035	Standard	CRC	Ref. CAD =E6829
11.	Coating from the previous sample	0.22	0.05	Standard	CRC	Ref. CAD =E6829

12.	Silicone rubber from a Bendix connector	1.05 0.39	0.09 0.063	Standard Standard	CRC CRC	from P. Townsend. from P. Townsend.
13.	Ty-rap (black)	3.6	0.025	Standard	SPAR	Polypropylene.
14.	Nylon ty-downs Nylon ty-downs Nylon ty-downs	0.3 0.3 0.28	0.03 0.01 0.01	Standard Standard Standard	CRC CRC CRC	As from the manufacturer wiped off with alcohol Ultrasonic 10 minutes dried at 100°C for 10 mins.
15.	Ty-rap Ty-rap Ty-rap	3.0 2.5 2.8	0.3 0.07 0.05	Standard Standard Standard	CRC CRC CRC	White from stores White from stores (NAME TAG) Not used for flight.
16.	Thermofit from RCA	0.68	0.34	Standard	CRC	Used for wire splice on DSA.
17.	Wire markers	3.5	0.9	Standard	CRC	Zip-strip. (Super Lanico Stranco products).

TABLE VI

Silicone Rubber (RTV)

Material	Weight Loss %	V C M %	Treatment	Source	Comments
RTV 11	2.1	0.25	Standard	CRC	Can. General Electric room temp. cure 3 days.
RTV 11	2.2	0.35	Standard	CRC	8 days cure.
RTV 11	1.6	0.25	Standard	CRC	15 days cure.
RTV 11	1.9	0.3	Standard	CRC	43 days cure.
RTV 11	1.8	0.33	Standard	CRC	61 days cure.
RTV 566A	0.20	0.03	Standard	CRC	6 days cure.

TABLE VII

Tapes

Material	Weight Loss %	V C M %	Treatment	Source	Comments
Kapton STSV128A2	1.6	0.54	Standard	Hamilton Standard	Kapton/silicone.
Kapton STSV128B5	1.6	0.48	Standard	Hamilton Standard	Aluminated Kapton/silicone.
Scotch tape 433	1.2	0.47	Standard	RCA	4 hours in a dry atmosphere.
Scotch tape 433	0.95	0.33	Standard	RCA	24 hours in a dry atmosphere.
Scotch tape 433	1.05	0.45	Standard	RCA	120 hours in a dry atmosphere.
3M – Y 9184A	1.7	0.04	Standard	RCA	Gold Kapton acrylic. 4 hours at room temperature
3M – Y 9184A	1.5	0.06	Standard	RCA	Gold Kapton acrylic. 24 hours at room temperature.
3M – 79	0.37	0.088	Standard	SPAR	Fibre-glass/acrylic.
8603-A-1	1.2	0.035	Standard	SPAR	Kapton/acrylic.
990B-2	0.25	0.156	Standard	SPAR	Sellotape.
8603-1	1.0	0.35	Standard	SPAR	Kapton/silicone. All cured at room temperature for 8 days.

TABLE VIII

Miscellaneous Materials

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	IMPCO RC2 IMPCO RC2	8.8 5.8	1.1 0.21	Standard Standard	RCA RCA	Impregnating resin of the SHF antenna (Used to fill microporosites in magnesium dish).
2.	Polyethylene Terephtalate	0.3	0.09	Standard	RCA	
3.	Raydite No. 75	1.3	0.011	Standard	RCA	
4.	Baxter Rubber Co. 1/64" silicone sheet	2.6	0.47	Standard	RCA	Proposed packaging material (not used in flight).
5.	Dow-Corning rubber sheet	1.04	0.07	Standard	RCA	
6.	Silicone grommet	1.6	0.26	Standard	CRC	J. Tennuci (Q.A.)
7.	Faurprene VS 0080	0.24	0.03	Standard		Viton coated polyester.
8.	Teflon coating	0.2	1.2	Standard	CRC	Spray coating: used to prevent corona breakdown in the TT+C transmitter, during launch phase.
9.	Painted Kapton	1.0	0.1	Standard	CRC	Paint (suspect).
10.	Velcro	0.6	0.12	Standard	SPAR	
11.	Fiber board	0.3	0.02	Standard	CRC	
12.	Cyanamid adhesive fiber HT 432	0.63	0.021	Standard		
13.	A1/7004	3.2	–	Standard	RCA	
14.	Kevlar RP 4002	2.5	0.04	Standard	RCA	

15.	A1-laminated shim. Plastic bonded adhesive paraplex P 43.	0.07	–	Standard	RCA	
16.	DC 61102 (Dow-Corning)	0.13	0.06	Standard	CRC	Thermal grease, used in battery assembly.
17.	Collar material	1.8	0.14	Standard	CRC	Material made by "Leigh Instruments" for CTS Spacecraft.
	Collar material	0.85	0.05	Standard	CRC	As above, with additional 16 heat cure at 70°C.
18.	Syntactic foam	0.65	0.04	Standard	SPAR	Used extensively to reinforce honeycomb structure for inserts etc.
19.	Silver filled grease (Chomeric)	2.02	0.22	Standard	CRC	
20.	Ecco-sorb foam 1.	8.1	0.375	Standard	CRC	Two layered material
	2.	6.0	0.4	Standard	CRC	1) Metal; 2) Blue foam.
21.	Silver filled grease (Chomeric)	0.4	0.03	6 days at 75°C at 10^{-6} torr	CRC	
22.	Carbon laminate with copper coating	0.06	0.02	Standard	CRC	
23.	V C 3	9.6	0.6	Standard	CRC	Oakland Corp. NYLOC Detroit Corp.
24.	C L P S	0.8	0.03	Standard	CRC	From Dr. Torrens. (FETA Projects).
25.	Nylon thermal blanket (shim material)	0.65	0.04	Standard	CRC	
26.	Ecco-sorb MF 5-124	0.23	0.05	Standard	CRC	
27.	Versamid-Epon 828 50/50	0.87	0.025	Standard	CRC	Nut-lock material, in general use on CTS.
28.	Kapton reinforced with fiberglass	0.4	0.09	Standard	CRC	CTS Solar array blanket material.

29.	Laminated board	0.35	0.02	24 hours at 75°C at 10^{-6} torr.	CRC	Originator B. Clarke.
30.	Carbon Fiber laminate (epoxy).	0.29	0.02	Standard	RCA	Waveguide material for CTS transponder. (V. O'Donavon)
31.	Sealant	0.6	0.18	Standard		This material was treated thermally for 20 mins. at 250°F.
32.	Styrofoam	Too large to record	0.4	Standard	CRC	Material shrank to a black powder.
33.	Cho-seal 1224	0.53	0.16	Standard	CRC	Silver impregnated silicone sheet.
34.	Chomeric 1215	0.67	0.10	Standard	CRC	Silver impregnated silicone sheet.
35.	Bel-Ray anti-seize	10.6	3.6	Standard	CRC	
36.	Moly-disulphide	1.2	0.15	Standard	CRC	Anti-seize compound.
37.	Chomeric 4220	1.0	0.15	Standard	CRC	Silver filled grease.
38.	Crown Flourocarbon spray	3.4	0.56	Standard	RCA	4 hours cure in air.
	Crown Flourocarbon spray	2.3	0.38	Standard	RCA	24 hours cure in air.
	Crown Flourocarbon spray	2.8	0.60	Standard	RCA	48 hours cure in air.
	Crown Flourocarbon spray	1.5	0.12	Standard	RCA	3 hours cure in air at 55°C.
	Crown Flourocarbon spray	1.66	0.15	Standard	RCA	3 hours cure in air at 55°C.
	Previous sample	3.29	0.41	plus 48 hours at 55°C at 10^{-6} torr. Standard	RCA	
39.	Dialco test lamp	0.72	0.41	Standard	RCA	From P. Schudderboom

TABLE IX

Paints

	Material	Weight Loss %	V C M %	Treatment	Source	Comments
1.	Paladin 'Inmont'	0.85	–	Standard	RCA	
	Paladin 'Inmont'	1.25	–	Standard	RCA	
	Paladin 'International'	4.8	–	Standard	RCA	
	Paladin 'International'	5.4	–	Standard	RCA	
2.	Paladin Laquer black 12412	9.0	1.3	Standard	RCA	3 coats cured at 200° C for 45 minutes between each application.
	Paladin Laquer black 12412	9.3	0.9	Standard	RCA	As above with 4 coats.
	Paladin Laquer black 12412	7.3	1.1	Standard	RCA	As above with 5 coats.

TABLE X

Outgassing Results: Honeycomb Samples

Sample	Original Mass (gm)	% Weight Change of Samples From Original Under Stated Conditions							
		At 80°C	At 80°C	At 80°C	19 hours At 80°C	10 hours At 125°C	At room temp.	At room temp.	At room temp.
A1 Face Sheet									
1.	19.1975	-0.10	-0.11	-0.13	-0.11	N/A	--	+0.02	+0.03
2.	16.8227	-0.12	--	--	-0.12	N/A	--	+0.01	+0.04
3.	16.9194	-0.12	-0.12	-0.13	-0.12	N/A	--	+0.02	+0.03
Fiberglass Face Sheet									
1.	18.3636	-0.55	-0.60	-0.60	-0.61	-0.65	+0.05	+0.15	+0.05
2.	15.0891	-0.52	--	--	-0.62	-0.67	- 0.10	- 0.02	- 0.09
3.	14.9614	-0.50	-0.56	-0.58	-0.58	-0.64	- 0.09	- 0.01	- 0.08

APPENDIX A

Equipment and Procedures for Determining the Amount of Volatile Materials Outgassed from Polymers under Satellite Environment Conditions

A-1 EQUIPMENT

Following a technique previously developed by SRI for screening of polymeric materials, a system for weight loss and VCM determination was designed and constructed, and is shown in Figure A-1. The unit was mounted in a 12" vacuum system, which could maintain a pressure of 10^{-6} torr.

The equipment basically consists of a solid copper block approximately 9" x 2" x 2", and a hollow water cooled block, on which are mounted polished copper plates for the collection of VCM. Both blocks are mounted on a single base-plate.

The temperature of the block may be controlled between room temperature and 150°C, with the cooling system at 25°C. The samples are contained in bored-out compartments in the solid copper block. The compartments are sealed by stainless steel plugs which screw down on to teflon washers. The heater soldered strategically in place to maintain uniform block temperature. The path from the sample compartments to the VCM collector plates is defined by a 1/4" diameter hole, the geometry of which is shown in Figure A-2. Cross contamination between compartments is avoided by the insertion of a baffle (not shown in the figure).

A-2 PROCEDURE

Products (e.g. foams, epoxies, conformal coatings etc.) which require compounding are mixed in batches of at least 100 grams to ensure a representative sample. Following appropriate cure or pre-treatment, these are cut into pieces not larger than 1/16" x 1/16" x 1" and used to make up the appropriate weights, except in the case of foams which are cut into blocks of the required weight. Total sample weight is normally < 200 mg. The samples are weighed on a precision micro-balance and placed in the sample compartments in pre-weighed aluminum boats where necessary (foams are inserted as is). The polished and cleaned copper collector plates are weighed on a micro-balance and fastened firmly in position on the cooling block by clips. The bell jar is set over the apparatus, and the system is evacuated to a pressure of less than 10^{-6} torr. The block is heated to the required temperature and maintained thus for a period of 24 hours. The block is allowed to cool to 50°C before being vented to air. The samples and collector plates are removed, and weighed once more using a micro-balance. From the results obtained, % total weight loss and % VCM's are calculated. Where

samples are to be collected for spectrometry, the appropriate material (usually quartz for visible and UV or Nacl for IR) is inserted in place of a copper plate.

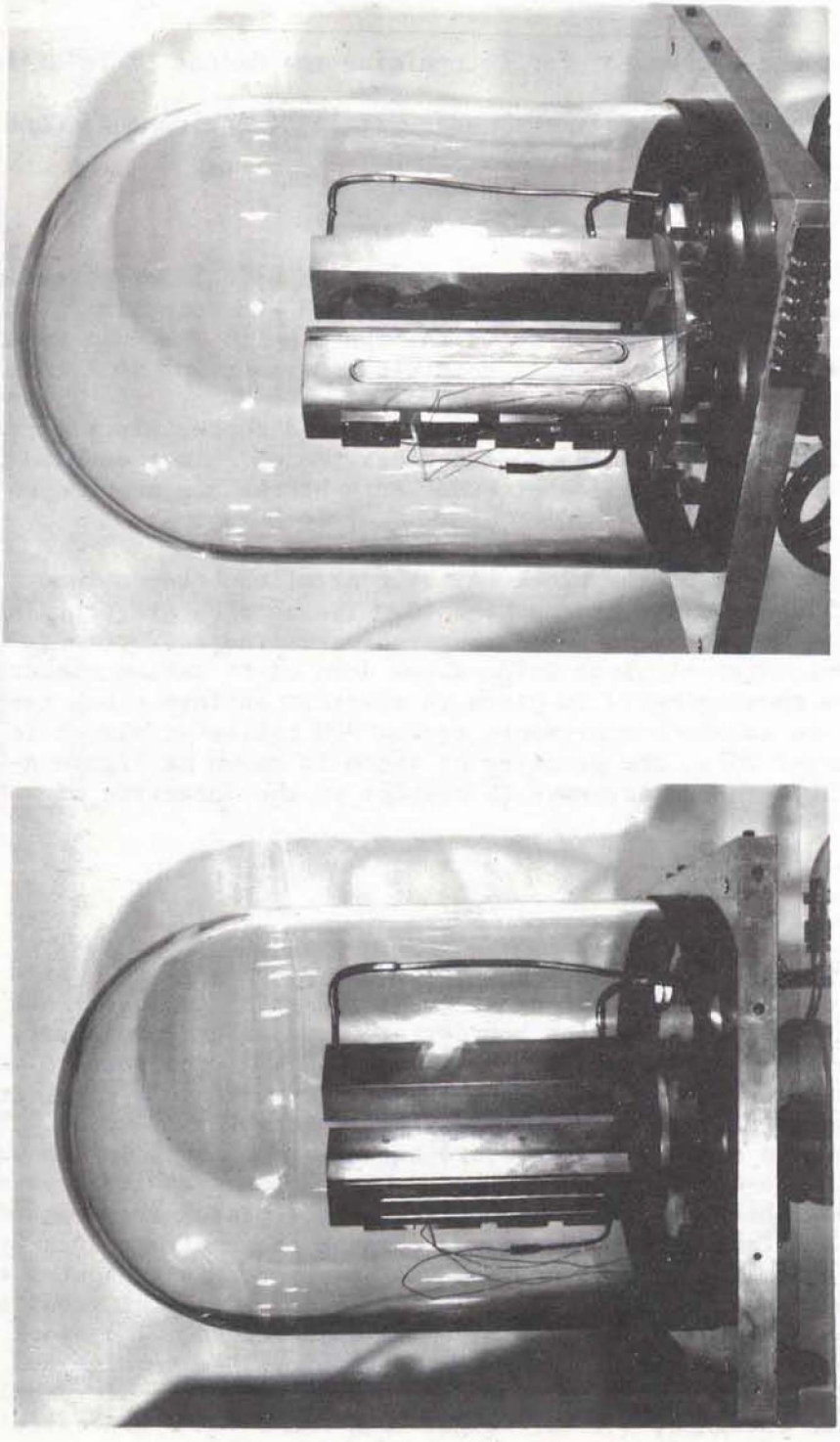

Figure A-1. Apparatus for Percent Weight Loss Plus Percent VCM Determination.

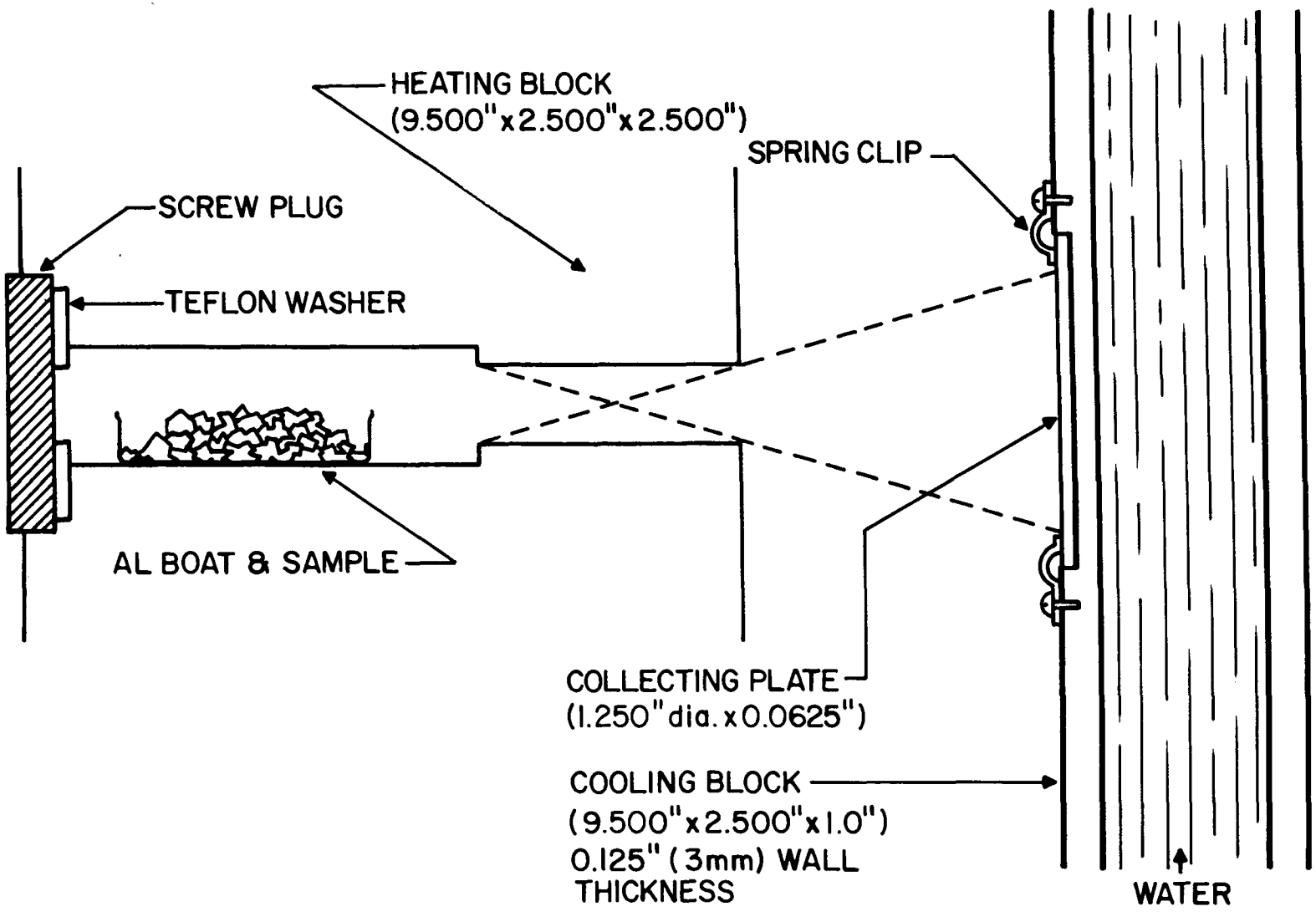

Figure A-2. Geometry of Apparatus for Percent Weight Loss Plus Percent VCM Determination.

APPENDIX B

Equipment and Procedures for Determining the Long Term Behaviour of Polymers Under Thermal Vacuum Conditions

B-1 EQUIPMENT

Following a technique similar to that described in a NASA Marshall SFC specification[9] for investigating the long term weight loss of polymers under controlled thermal conditions, an electrobalance (Cahn 2000RC) was installed in a vacuum system which would maintain a pressure of 10^{-6} torr, as shown in Figure B-1. A small cylindrical heater was installed, attached to a mobile feed-through, to allow the weighing pan of the balance, and hence the sample, to be heated to the desired temperature with immediate control. The heater was equipped with an iron-constantan thermocouple to record the temperature in the locale of the sample (1 mm below). The output from the balance and the thermocouple are fed to a recorder. Using this method, the weight loss of the polymers may be continuously recorded versus time at known temperatures and pressures.

B-2 PROCEDURE

The micro-balance is turned on and allowed to "warm-up" for a period of 18 hours, and then calibrated. Samples of the material to be tested (between 200 and 500 mg) are placed in the balance pan, and the weight recorded. The heater is located in position with the thermocouple approximately 1 mm below the pan as shown in Figure B-2, and the bell jar is evacuated to a pressure of 10^{-6} torr. Continuous weight measurements may be taken from this time onward. Heat may be applied to the sample any time during the operation either continuously or for controlled periods of time. The heat cycle can be plotted using the same time cycle as used for the weight loss plot; and from the combined information, a comprehensive analysis of the behaviour of the material undergoing the test can be made.

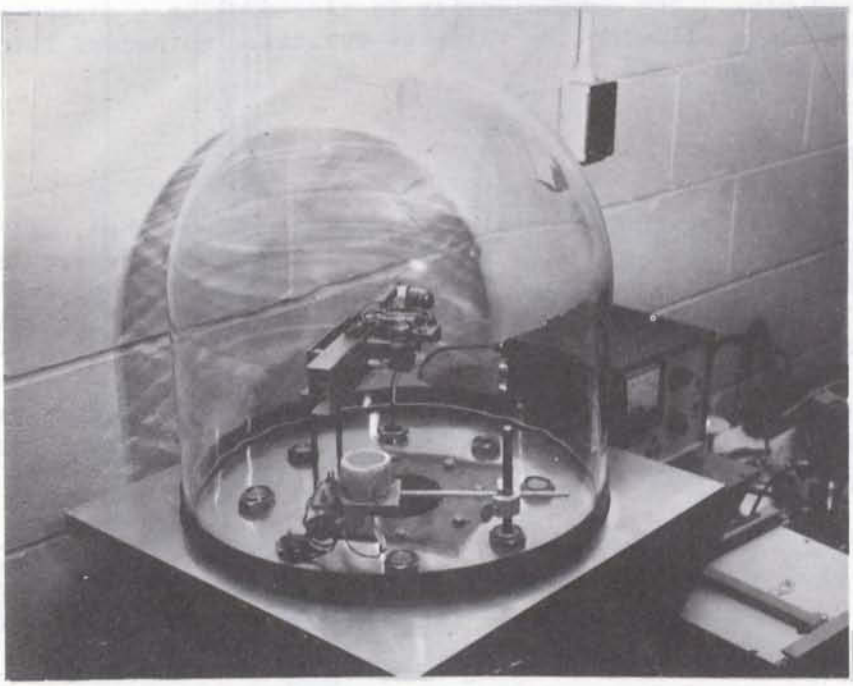

Figure B-1. Apparatus for Long Term Outgassing Studies.

APPENDIX C

Equipment and Procedures for Identifying Materials Outgassed From Polymers Under Thermal Vacuum Conditions Via Mass Spectrometry

C-1 EQUIPMENT

Following a technique employed by NASA-MSFC outgassing specification[9], an ultra-high vacuum system (Aero-vac Model 4193) equipped with a mass spectrometer (Balzer QMG 101A) was fitted with a heated sample holder (Figure C-1) using a 2 3/4" flange. The holder consists of a cylindrical copper block 1" diameter and 1 3/4" long, bored out to form a sample cavity, 1/4" diameter by 1" deep; and a smaller cavity for a thermocouple. An 'Xactglo' sheathed wire heater was wound into position and silver-soldered to the block. The block was mounted on a four-pin feed-through using a stainless steel rod. An iron-constantan thermocouple was situated in the block, and the leads from the latter and the heater silver-soldered to the respective feed pins. The sample cavity is closed using a copper plate with a small central hole allowing the released volatiles to escape into the vacuum chamber for analysis.

C-2 PROCEDURE

Small samples of the material to be tested are weighed, using a micro-balance (accurate to 10^{-5} g). The sample is loaded into the sample holder cavity and the holder is assembled into the vacuum chamber and then sealed. The chamber is then evacuated to a pressure of 10^{-6} torr and analysis may be started. Heat application can be made as required.

Analysis may be made either by identification of cracking patterns, or by monitoring of single peaks (e.g. H_2O, N_2, etc.) over long periods of time, at various temperatures.

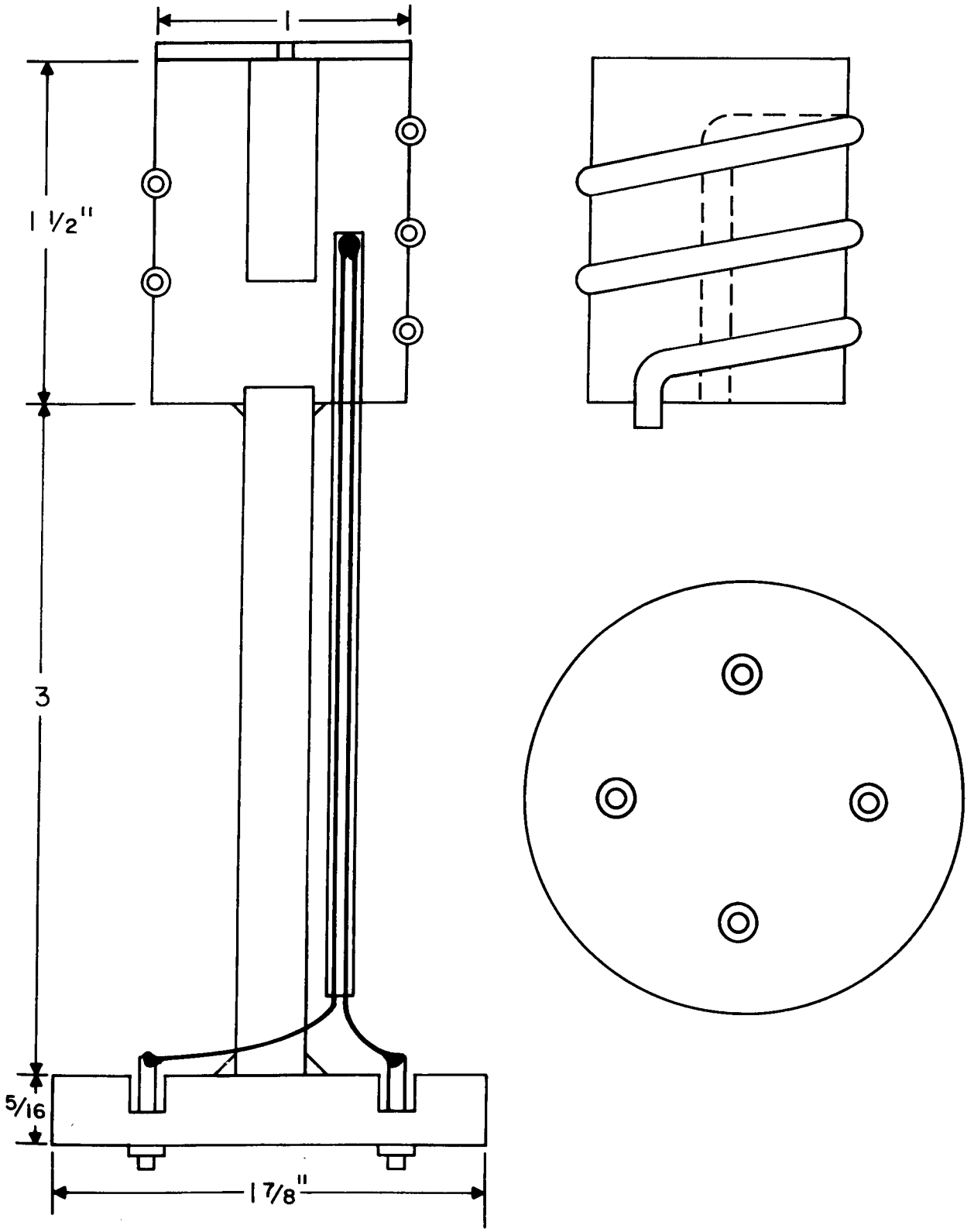

Figure C-1. Heater Sample Holder for Ultra High Vacuum Outgassing Studies.

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7. **SUBJECT CATEGORY (FIELD & GROUP: COSATI)**

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8. **ABSTRACT:**

This report describes work carried out on the outassing properties of proposed spacecraft materials as part of the Communications Technology Satellite (CTS) Project. The rationale for the tests is stated, and equipment design and experimental methods are described. Results of tests carried out on specific materials are given for each class of material, categorized as to type or use. The relevance of the results to CTS experience is briefly discussed.

9. **CITATION:**

Government of Canada Gouvernement du Canada