

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

UNCLASSIFIED

APOLLO

GUIDANCE AND NAVIGATION

FOR OFFICIAL USE ONLY

~~This document has been prepared for instrumentation laboratory use and for limited external distribution. Reproduction or further dissemination is prohibited without express written approval of MIT. This document has not been reviewed by the Security Classifications Office, NASA, and the State Department.~~

(NASA-CR-129904) COMBUSTION OF POLYOLEFIN
INSULATION AND TOXICITY OF TEFLON UNDER
ELECTRICAL OVERLOADS A.O. Mirarchi
(Massachusetts Inst. of Tech.) Dec.
1964 41 p

N73-70034

Unclas

00/99 39685

E-1713

COMBUSTION OF POLYOLEFIN
INSULATION AND TOXICITY
OF TEFLON UNDER
ELECTRICAL OVERLOADS

by

A. O. Mirarchi

December 1964

MIT

**INSTRUMENTATION
LABORATORY**

CAMBRIDGE 39, MASSACHUSETTS

UNCLASSIFIED

MAY 14 1965

APOLLO

GUIDANCE AND NAVIGATION

Approved: Milton B. Trageser Date: 1/6/65
MILTON B. TRAGESER, DIRECTOR
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved: Roger B. Woodbury Date: 1/13/65
ROGER B. WOODBURY, DEPUTY DIRECTOR
INSTRUMENTATION LABORATORY

E-1713

COMBUSTION OF POLYOLEFIN
INSULATION AND TOXICITY
OF TEFLON UNDER
ELECTRICAL OVERLOADS

by

A. O. Mirarchi

December 1964

MIT INSTRUMENTATION
LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

COPY # 51

Technical Library, Bellcomm, Inc.

ACKNOWLEDGMENT

This experimental work was designed at the Instrumentation Laboratory, MIT, under DSR Project 55-191, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-153.

The work was conducted at Parametrics, Inc., Waltham, Massachusetts, under P/O No. IL-B 79285.

The preparation and baking of Teflon insulated wires was done at the Instrumentation Laboratory by Mr. M. Soikkeli, while the Mass Spectrometric Analyses of the pyrolysis products of these samples were done by Dr. Paul Vouros, under the direction of Professor Klaus Biemann, Chemistry Department, MIT.

The assistance of Mr. George Reickert and of Mr. Stephen Dismar is gratefully acknowledged for their part in this work during the summer of 1964.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

SUMMARY

Test were conducted on polyolefin insulated #24 gauge wires to determine conditions of insulation breakdown, ignition, and explosion. Some wires were treated with a water-repellant-type-coatings.

Test conditions in single strands of wire included

- (a) an open flame,
- (b) at pressure of 1/3 atmosphere in static oxygen with vessel externally heated up to 725^oF, and
- (c) at ambient atmosphere with wire heated internally by current of 10, 15, 20, and 25 amps.

Bundles of three insulated wires inside a plastic sleeving material were tested at 1/3 atmosphere with internal current heating in one wire ranging to 34 amps.

- (a) in static oxygen
- (b) in oxygen flowing at 3 liters/min, and
- (c) in oxygen flowing at 6 liters/min:

A bundle of three wires in a copper braid sleeve was tested under similar conditions.

Bundles of thirteen wires were tested with internal current heating of about 30 amps (except as noted).

- (a) under ambient atmosphere (with 10 to 33 amps)
- (b) at 1/3 atmosphere in static oxygen
- (c) at 1/3 atmosphere in oxygen flowing at 1 liter/min,
- (d) at 1/3 atmosphere in oxygen flowing at 3 liter/min,
- (e) at 1/3 atmosphere in oxygen flowing at 6 liter/min,
- (f) inside plastic sleeving at 1/3 atmosphere in oxygen flowing at 3 liters/min,
- (g) in copper mesh at 1/3 atmosphere in oxygen flowing at 3 liter/min.

One bundle of forty-three wires in a plastic sleeve was tested at 1/3 atmosphere in oxygen flowing at 3 liters/min with 30 amp current in one central wire.

In addition, one bundle of thirteen Teflon-polyamide insulated #22 gauge wire was tested at 1/3 atmosphere in oxygen flowing at 3 liters/min with a 30 amp current in a central wire. Finally, these same conditions were applied to a similarly insulated bundle of thirteen #24 gauge wires.

The following Summary Table shows the various tests and test conditions, with reference to the particular detailed table in the text. All observations made are included in the respective tables.

SUMMARY TABLE

| Run No. | Number of Wires | Treatment | | Pressure (atm) | Heating | | | Environment | | | Reference Table No. | |
|-----------------------------------|----------------------|-----------|--------|----------------|------------|---------------|------------------|-------------|---------------|--------------------------|---------------------|--------|
| | | None | L-1483 | | Open Flame | External Tape | Internal Current | Ambient | Static Oxygen | Dynamic Oxygen Liter/min | | Sleeve |
| A. Polyolefin insulation, #24 AWG | | | | | | | | | | | | |
| 1-4 | Single, 3" | X | X | Ambient | | | | | | | | 3 |
| 1-4 | Single, 3" | X | X | Ambient | | | | | | | | 3 |
| 1-2 | Single, 3" | X | X | Ambient | | | | | | | | 4 |
| 1-2 | Single, 3" | X | X | 1/3 | | | | | | | | 4 |
| 1-2 | Single, 3" | X | X | 1/3 | | | | | | | | 5 |
| 3 | Single, 3" | X | X | 1/3 | | | | | | | | 6 |
| 1 | Thirteen, 3" | X | X | Ambient | | | | | | | | 6 |
| 2 | Thirteen, 3" | X | X | Ambient | | | | | | | | 7 |
| 1-2 | Thirteen, 3" | X | X | 1/3 | | | | | | | | 7 |
| 3 | Thirteen, 3" | X | X | 1/3 | | | | | | | | 7 |
| 1 | Three, 7" | X | X | 1/3 | | | | | | | | 8 |
| 2-3 | Three, 7" | X | X | 1/3 | | | | | | | | 8 |
| 4 | Three, 7" | X | X | 1/3 | | | | | | | | 9 |
| 5 | Three, 7" | X | X | 1/3 | | | | | | | | 9 |
| 1 | Three, 7" | X | X | 1/3 | | | | | | | | 9 |
| 2 | Three, 7" | X | X | 1/3 | | | | | | | | 10 |
| 1 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 10 |
| 2 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 11 |
| 1-2 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 11 |
| 1-2 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 12 |
| 1 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 13 |
| 2 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 14 |
| 3 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 14 |
| 1 | Forty-three, 7" | X | X | 1/3 | | | | | | | | 15 |
| 1 | Thirteen, 7" | X | X | 1/3 | | | | | | | | 15 |
| 2 | Three, 7" | X | X | 1/3 | | | | | | | | 16 |
| B. Teflon-polyamide insulation | | | | | | | | | | | | |
| 1 | Thirteen #22 AWG, 7" | X | X | 1/3 | | | | | | | | 17 |
| 1-2 | Thirteen #24 AWG, 7" | X | X | 1/3 | | | | | | | | 18 |

CONCLUSIONS AND RECOMMENDATIONS

The condition of electrical overloading of wires, having different insulation materials, leads to the formation of gaseous mixtures between the products formed by the pyrolytic degradation of the insulation and the oxygen (or other) atmosphere surrounding them. These gaseous mixtures can be combustible, as is the case when hydrocarbons are given off from polyolefin insulation. Or they may be noncombustible, as is the case when fluorocarbons are given off from the Teflon. Combustion will occur, in the case of hydrocarbon and oxygen mixture, only if the mixture falls within the limits ranging from fuel-rich to oxygen-rich-mixture and, at the same time, a hot spot of about 1000°C temperature is present which can trigger the ignition. While the hydrocarbons are not toxic, the fluorocarbons are toxic; hence, this additional hazard must be recognized in the confines of the space capsule.

Consequently, the need is indicated for a conservative approach in the electric and electronic design of all equipments on board to provide automatic fail-safe features. Wiring should be selected on the basis of anticipated overloads. Where this condition could happen, the insulation should be of a nontoxic, noncombustible nature, such as glass or asbestos insulation, and, additionally, these circuits should be kept physically separated from all others.

SECTION 1

INTRODUCTION

The tests undertaken for this work were made for the purpose of obtaining confirmation on the expected behavior of wire insulation materials when heated, by electrical overloading, in an atmosphere of oxygen. The atmosphere of the Command Module for the Apollo mission is composed of oxygen, at a pressure of 5 psi. Superposed to this, an anticipated (temperature dependent) moisture component of 1 to 2 psi will be established soon after launch, due to fluids and humans on board. This moisture component has not been introduced in the tests herein reported because of the time requirements for obtaining the test data, and because it is believed that such an additional moisture component would have complicated considerably the test procedure and instrumentation, without changing the basic findings. The selection of electrical insulation materials to be tested was based essentially on the fact that, chronologically, the irradiated polyolefins (Thermorad) had been selected as suitable and acceptable on the basis of their other desirable properties as wire insulation materials (cut-through, thickness, density, insulation resistance, radiation resistance, etc). Teflon insulation was tested to obtain a comparison versus irradiated polyolefins with respect to combustibility and toxicity. The Teflon-polyamides (Kynar) were tested, as a few samples became available, again for the purpose of comparison, inasmuch as this combination of insulation materials showed desirable properties falling between those of Teflon alone, and those of irradiated polyolefins.

The reader will notice that electrical overloading was at first attained by increasing the amount of current flowing through the wires in some arbitrary increments of time and of current. This was done deliberately to get a feel for the most desired way in which to conduct the tests. In general, such step-wise procedure leads to a higher tolerance by the system for the overload, because the system has time in which to dissipate thermal energy through mechanisms of radiation, conduction, and convection. A proper technique for these studies would seem to be one in which overloading would be accomplished exactly as it might occur during operation of the electrical-electronic equipments on board: i. e. , the intensity, the frequency, and the

duration of the overloads should be duplicated in wires of the same make and gauge as those used in the actual circuits.

Another point of considerable importance must be made of the techniques referred to in this report as "static" or "dynamic" oxygen. The former means that the experimental vessel was given an initial charge of oxygen to the desired pressure, 5 psi. The latter means that inlet and outlet valves of the experimental vessel were manipulated to obtain the desired oxygen pressure in the vessel while oxygen was flowing. The former technique leads to the formation of combustible mixtures of oxygen and fuel (distillate from the wire insulations) ranging widely in composition, and showing some typical relationship between composition of the gaseous mixtures and wire temperatures. The latter technique leads to the formation of an entirely different set of corresponding values.

These two different techniques can be summarized and generalized by noting that the static tests showed no combustion, i. e., the attainment of combustible gaseous mixture between distillate and oxygen occurred before the wires were hot enough to trigger combustion; and, at a later time, when the wires became hot enough to trigger the combustion, this could not occur because the gaseous mixture was fuel-rich.

The dynamic tests showed violent combustion because even though some of the fuel was being continuously swept out of the experimental vessel, the rate of distillation was continuously increasing as the wire got hotter, and the oxygen was continuously being replenished until eventually the wire temperatures reached the ignition point of the oxygen-fuel mixtures.

Analogous conditions to these described can be expected to be generated on board, depending on circulation of the Command Module atmosphere, on the ventilation, or lack of it, in some recessed part of the equipment, and on the interplay between the mechanisms of radiation, conduction, and convection in dissipating the heat generated in one or more wires.

SECTION 2

PROCEDURE AND RESULTS

2.1 Application of Retardant to Cables

Water repellent L-1483 is available from Minnesota Mining and Manufacturing Co. The suspension as received from the manufacturer was diluted to achieve a desired coating thickness. All coatings at the MIT/IL laboratory were applied from a mixture of 13.3 gms of L-1483 (as received from the manufacturer) and 86.7 gms of a 4:1 solution of 1, 1, 1 trichlorethane and methyl ethyl ketone. This mixture resulted in a 2% L-1483 solution.

The polyolefin wires were dipped in this solution and withdrawn at a time rate of approximately three seconds per inch. This procedure insured uniformity and reproducibility of the coating.

Before applying the retardant to the wires, the wires were vapor degreased with trichloroethylene. The insulated wires were exposed to trichloroethylene fumes at 80 to 90°C for approximately one hour. Three inch lengths of the 24-gauge wire were weighed before and after dipping in the L-1483 solution. The curing time at room temperature was approximately sixteen hours. A comparison of the amount of L-1483 coating adhered to wires degreased and not degreased is shown in Table 2.1.

TABLE 2.1

Effect of Amount of L-1483 Adhered When Degreased with Trichloroethylene.

| Not Degreased | | Degreased | |
|---------------|----------------|-----------|----------------|
| Wire No. | Wgt. of L-1483 | Wire No. | Wgt. of L-1483 |
| 1 | 0.0 mg | 4 | 0.5 mg |
| 2 | 0.3 mg | 5 | 0.6 mg |
| 3 | 0.5 mg | 6 | 0.6 mg |

Although a more uniform and reproducible coating of the retardant is obtained when the wire is degreased with trichloroethylene, this solvent swells the polyolefin insulation to 50 percent of its original size. When

drying, a 16-percent reduction in the length of the original insulation was observed.

A similar procedure was followed using methyl ethyl ketone as the degreasing solvent. The insulation did not swell when exposed to these vapors, nor was any shrinkage observed upon drying. The wires were degreased with methyl ethyl ketone by vapor degreasing as well as by wiping with a paper tissue saturated with this solvent. The results are shown in Table 2.2.

TABLE 2.2

Amount of L-1483 Adhered When Degreased With Methyl Ethyl Ketone.

| Vapor Degreased | | Wiped with MEK | |
|-----------------|----------------|----------------|----------------|
| Wire No. | Wgt. of L-1483 | Wire No. | Wgt. of L-1483 |
| 1 | 0.5 mg | 1 | 0.6 mg |
| 2 | 0.6 mg | 2 | 0.6 mg |
| 3 | 0.5 mg | 3 | 0.5 mg |

In all subsequent coating applications, the wires were degreased by wiping the insulation with a paper tissue saturated with methyl ethyl ketone.

2.2 Preliminary Experiments to Determine Ignition of Temperature and Currents.

2.2.1 Ambient Conditions

The effect of an open flame on treated (in all subsequent discussions "treated" indicates a coating of L-1483 had been applied) and untreated polyolefin cables was determined. An open flame (propane torch) was maintained five inches from a single strand of wire. A thermocouple was placed in contact with the insulation of this wire. These open flame experiments were conducted under normal atmospheric conditions. The results of these experiments are shown in Table 2.3.

TABLE 2.3

Open Flame Experiments, Ambient Atmosphere

| Treated Wires | | | Untreated Wires | | |
|---------------|------------------------------------|-------------------------|-----------------|------------------------------------|-------------------------|
| Run | Ignition Temp (^o F) | Time to Ignite (sec) | Run | Ignition Temp (^o F) | Time to Ignite (sec) |
| 1 | 1050 | 10 | 1 | 1100 | 18 |
| 2 | 1150 | 8 | 2 | 1050 | 7 |
| 3 | 1100 | 10 | 3 | 1100 | 15 |
| 4 | 1050 | 12 | 4 | 1050 | 8 |

Under the conditions of the above experiment the wires continued to burn while in proximity of the torch. Removal of the torch caused a cessation of the flame in both the treated and untreated samples.

The charring temperature and current were determined under ambient conditions. Wires three inches in length were successively connected in series to an ammeter and a 50-amp Variac. Currents of 10, 15, 20 and 25 amps were passed through each wire. The temperature at the surface of the wire was determined using temperature-sensitive paints. The wire was held for 120 seconds at each current setting. The results of treated and untreated wires subjected to identical conditions are shown in Tables 2.4.

TABLE 2.4

Internally Heated Wires, Ambient Atmosphere

| Current (amps) | Temperature (^o F) | Untreated | Treated | |
|-------------------|----------------------------------|---------------------------|---------------------------|---------------------------|
| | | Observations | Run 1 Observations | Run 2 Observations |
| 10 | 140 | No change | No change | No change |
| 15 | 160 | No change | No change | No change |
| 20 | 200 | No change | No change | No change |
| 25 | 400 | Yellow Dis- coloration | Yellow Dis- coloration | Yellow Dis- coloration |

2.2.2 Tests in One-Third Atmosphere of 100% O₂

Individual strands of wire three inches in length were mounted in the test apparatus shown in Fig. 2.1. The reaction vessel was evacuated by means of a fore pump to approximately 10^{-3} torr. One hundred percent oxygen was then introduced to a pressure of 1/3 of an atmosphere (10 in. of Hg). The vessel was isolated by means of a valve; hence, the increases in pressure noted are attributed to volatiles distilled from the wire insulation. The insulated wire was heated in the reaction vessel from the outside by a heating tape encompassing the vessel. The results of this external heating on untreated wires under static conditions are shown in Table 2.5.

TABLE 2.5

Untreated Wires Externally Heated in O₂ at 1/3 Atmosphere.

| Run 1 | | | Run 2 | | |
|------------|----------------------|------------------------------|------------|----------------------|------------------------------|
| Temp. (°F) | Pressure (in. of Hg) | Observation | Temp. (°F) | Pressure (in. of Hg) | Observation |
| 200 | 10 | No change | 75 | 10 | No change |
| 300 | 11 | No change | 167 | 10.5 | No change |
| 350 | | No change | 200 | 11 | No change |
| 400 | 12 | Yellowing | 300 | 11.2 | No change |
| 450 | | Browning | 350 | 11.6 | No change |
| 500 | 12.4 | Dark Brown | 400 | 11.9 | Browning |
| 550 | | Very Dark Brown | 450 | 12.1 | Browning |
| 600 | 13.0 | Black | 500 | 12.3 | Dark Brown |
| 625 | | Black | 550 | 12.8 | Dark Brown |
| 650 | | Black | 600 | 13.0 | Very Dark Brown |
| 700 | 13.5 | Tarry (fusing of insulation) | 650 | 13.2 | Brown Black |
| 725 | | Tarry (fusing of insulation) | 700 | 13.5 | Black |
| | | | 800 | 14.1 | Tarry (fusing of insulation) |
| | | | 850 | 14.3 | Tarry (fusing of insulation) |
| | | | 900 | 15 | Tarry (fusing of insulation) |
| | | | 950 | 15 | Tarry-Bubbling |
| | | | 1000 | 15 | Tarry-Bubbling |

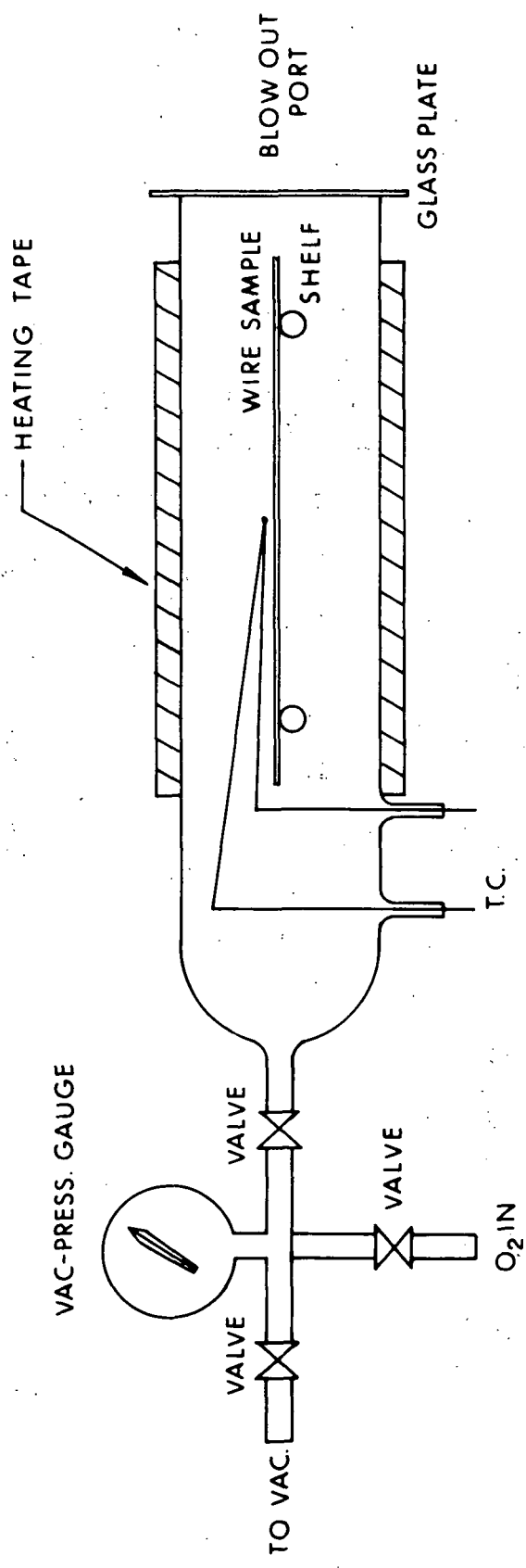


Figure 2.1 Externally Heated Glass Apparatus.

The identical test apparatus was used to determine the effect of wires treated with L-1483 by external heating under static conditions. These results are shown in Table 2.6. Runs #1 and #2 were conducted with wires which had been coated once with L-1483. Run #3 was conducted with a wire which had been coated three times with L-1483.

TABLE 2.6

Treated Wires Externally Heated in 1/3 atm of O₂.

| Temp. (°F) | Pressure (in. of Hg) | Observations | Temp. (°F) | Pressure (in. of Hg) | Observations |
|--|----------------------|----------------|---------------------------------------|----------------------|----------------|
| <u>Run 1 - (1 coating of L-1483)</u> | | | <u>Run 3 - (3 coatings of L-1483)</u> | | |
| 75 | 10 | No change | 75 | 10 | No change |
| 200 | 10.5 | No change | 200 | 11 | No change |
| 300 | 11.2 | No change | 300 | 11.7 | No change |
| 400 | 11.7 | Discoloration | 400 | 12 | No change |
| 500 | 12.0 | Brown | 450 | 12.2 | Discoloration |
| 600 | 12.6 | Dark Brown | 500 | 12.5 | Brown |
| 700 | 13.0 | Black | 600 | 13.0 | Dark Brown |
| 800 | 13.7 | Black | 650 | 13.5 | Dark Brown |
| 900 | 13.5 | Tarry | 700 | 13.8 | Brown-Black |
| 950 | 13.0 | Tarry-Bubbling | 750 | 14. | Black |
| 1000 | 13.0 | Tarry-Bubbling | 800 | 14.2 | Tarry |
| 1050 | 13.0 | Tarry-Bubbling | 850 | 14.7 | Tarry |
| | | | 900 | 15.0 | Tarry-Bubbling |
| | | | 925 | 15.0 | Tarry-Bubbling |
| <u>Run 2 - (1 coating of L-1483)</u> | | | | | |
| 400 | 11.0 | No change | | | |
| 450 | | Discoloration | | | |
| 500 | | Brown | | | |
| 550 | | Brown | | | |
| 600 | | Dark Brown | | | |
| 700 | 13.0 | Dark Brown | | | |
| 725 | | Black | | | |
| 800 | 14.0 | Tarry | | | |
| 850 | | Tarry-Bubbling | | | |

2.3 Final Experiments

2.3.1 Ambient Conditions

Thirteen untreated wires of three-inch lengths were formed into a bundle of parallel wires. The polyolefin-insulated twenty-four gauge wires were bound with bus wire for rigidity. The central wire of the bundle was connected in series to an ammeter and a 60-amp Variac. Two thermocouples were placed in contact with the bundle, one in the center of the bundle in the proximity of the central wire (internal temperature) and one on the surface of the bundle (external temperature). Current was passed through the central wire in increasing steps of 5 amps, each step being maintained for a three-minute time period. A similar bundle of thirteen treated wires was constructed and tested under identical conditions. These experiments were conducted in room air under ambient conditions. The results are shown in Table 2.7.

TABLE 2.7

Bundles of Thirteen Wires Under Ambient Conditions.

| Internal Temp. (°F) | External Temp. (°F) | Current (amps) | Time (min) | Observations |
|---------------------|---------------------|----------------|------------|----------------------|
| <u>Untreated</u> | | | | |
| 100 | 95 | 10 | 3 | No change |
| 140 | 100 | 15.5 | 6 | No change |
| 175 | 125 | 19.5 | 9 | No change |
| 250 | 140 | 24 | 12 | Discoloration |
| 380 | 155 | 29 | 15 | Brown Discoloration |
| 800 | 170 | 32.5 | 16 | Charring-Heavy Smoke |
| <u>Treated</u> | | | | |
| 110 | 95 | 10 | 3 | No change |
| 150 | 100 | 15 | 6 | No change |
| 170 | 120 | 20 | 9 | No change |
| 260 | 150 | 25 | 12 | Brown Discoloration |
| 400 | 155 | 30 | 15 | Black Discoloration |
| 925 | 180 | 33 | 15.5 | Charring-Heavy Smoke |

2.3.2 Tests in One-Third Atmosphere of 100% O₂

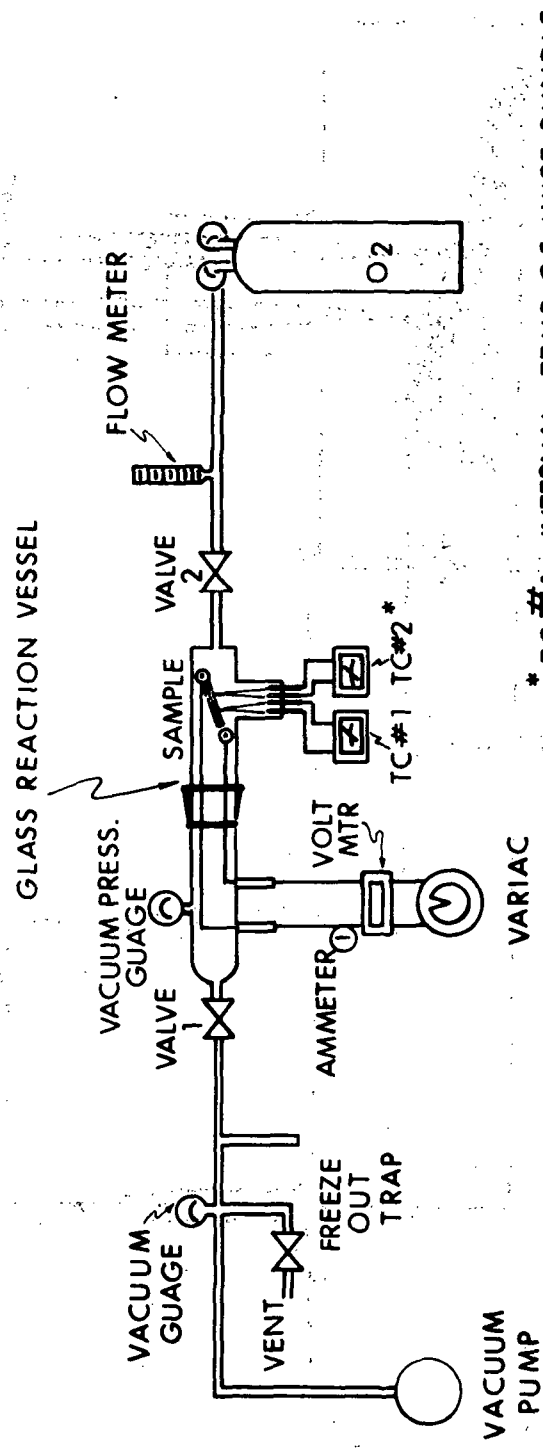
a) Glass Test System

The initial apparatus used to ignite by electrical overloading and to evaluate L-1483 as a fire retardant for bundles of irradiated polyolefin insulated wires is shown in Figure 2.2. This test system is constructed almost entirely of glass. The glass reaction vessel can be operated under either static or dynamic conditions. For a static test, the vessel is evacuated to approximately 10^{-3} torr by means of the fore-pump. Valve 1 is then closed and 100% O₂ is introduced through Valve 2 until the vacuum gauge indicates a pressure of 1/3 atm, at which point valve 2 is closed. The vessel is then ready for the static test.

For a dynamic test, the vessel is first evacuated to a pressure of 10^{-3} torr. Oxygen is then bled into the vessel until the vacuum gauge indicates 1/3 atm of oxygen. Valve 1 and Valve 2 are then manipulated to maintain the pressure constant while oxygen is being fed continuously into the vessel. The flow rate through the system is determined by the difference in flowmeter reading with valve 2 closed and opened at the desired operating conditions. (The excess flow is exhausted through the flowmeter which also serves as a vent). The vessel is then ready for the dynamic test.

An enlarged drawing of the reaction vessel itself is shown in Figure 2.3. Current is carried to the test bundle by 12 gauge copper wire. Thermocouples #1 and #2 measure the external and internal temperatures respectively. A blow-off window was provided to prevent destruction of the apparatus in the event of an explosion. (As seen below, this blow-off window proved inadequate).

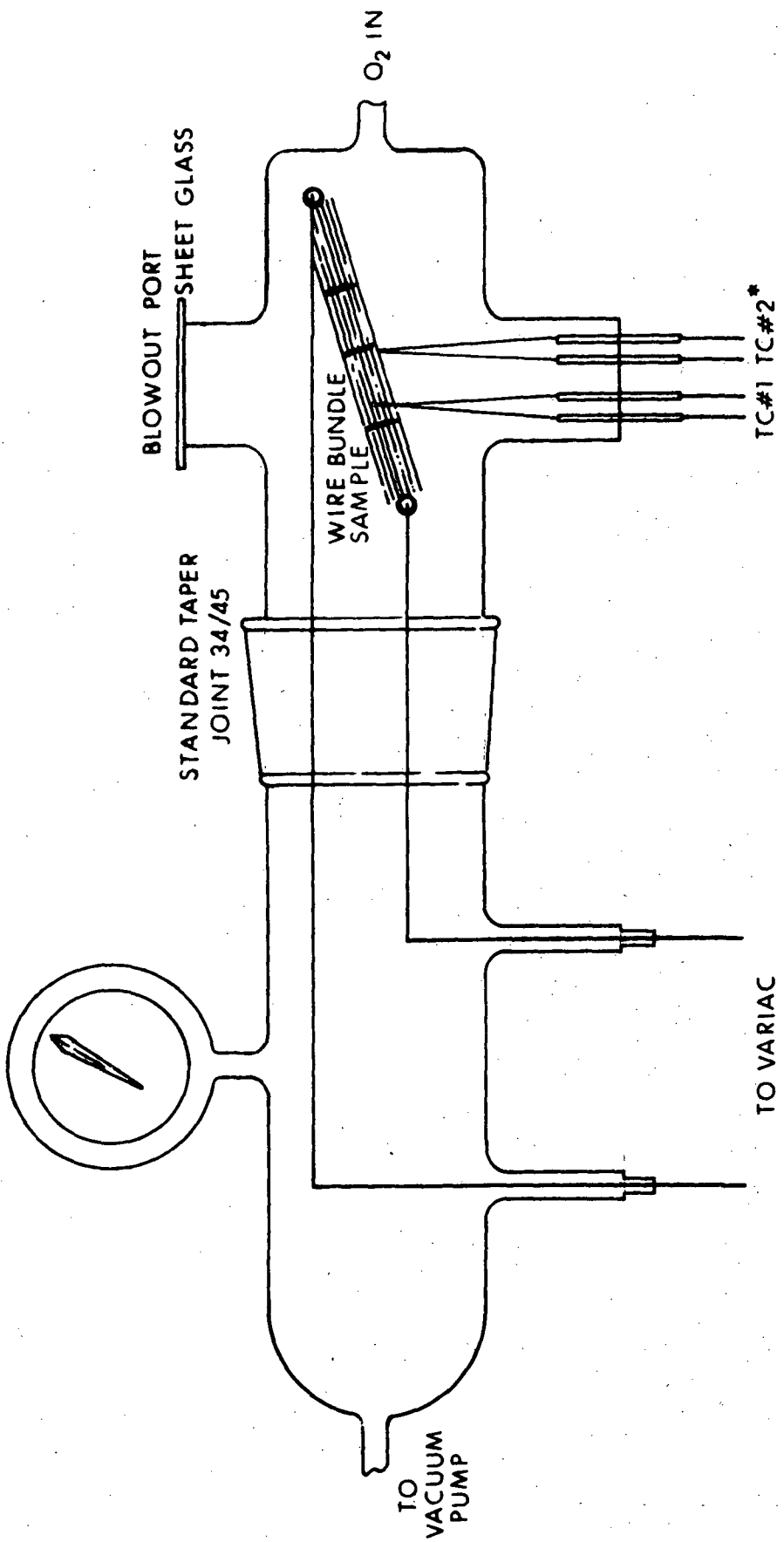
Three runs were made with this system, all with bundles of thirteen untreated wires of three-inch lengths. In the first run, the current was gradually increased in steps of approximately 5-amp intervals. The vessel was maintained in a static condition. The second run was also a static test, only this time the current was raised to 34 amps immediately. The third run was a dynamic test with flow rate of



* TC #1 INTERNAL TEMP. OF WIRE BUNDLE
 TC #2 EXTERNAL TEMP. OF WIRE BUNDLE

Figure 2.2 Glass Test System.

VACUUM-PRESSURE GAUGE



- * TC#1 Internal Temp.
- * TC#2 External Temp.

Figure 2.3 Glass Reaction Vessel.

1 liter/min at 1/3 atm oxygen. The current was raised immediately to 33 amps. In this last run an explosion occurred, shattering the apparatus. The results of these three runs are shown in Table 2.8.

TABLE 2.8

Bundle of Thirteen Untreated Wires in 1/3 Atmosphere O₂.

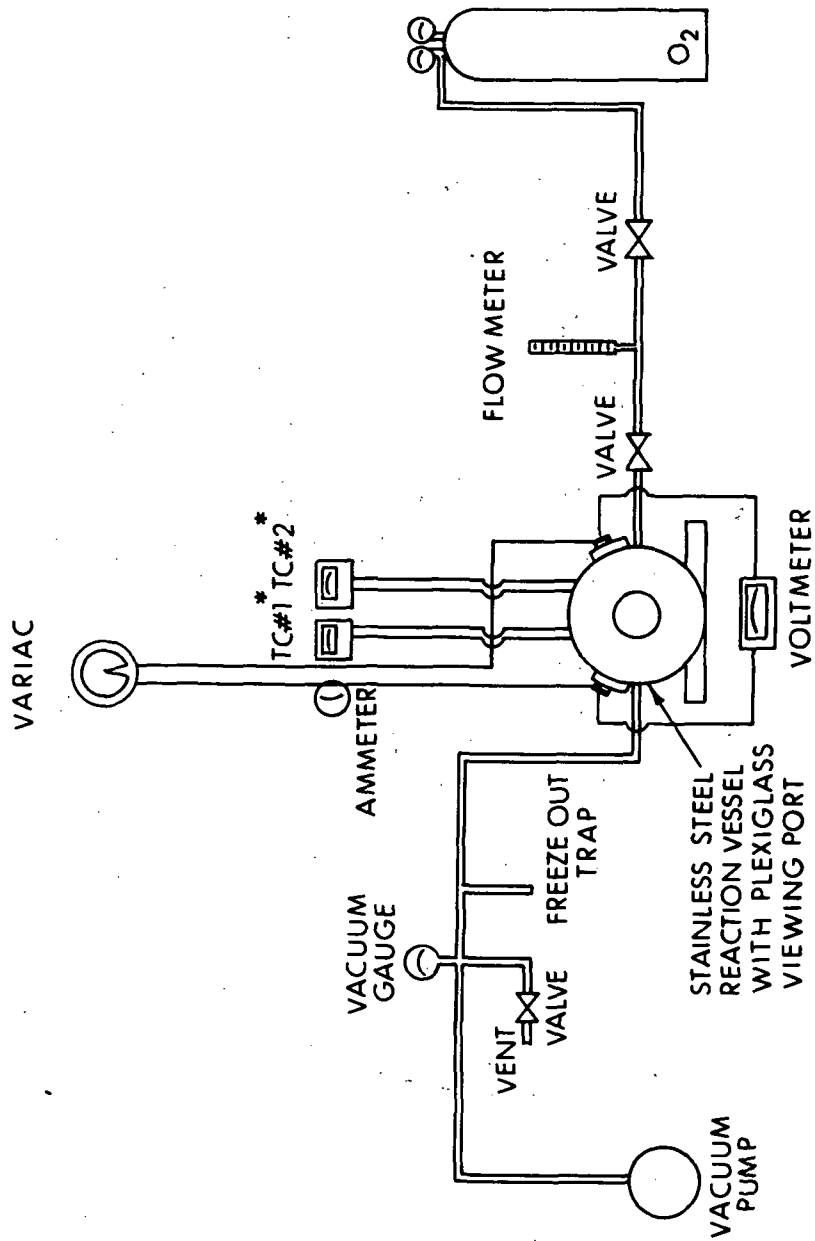
| Internal Temp. (°F) | External Temp. | Pressure (in. of Hg) | Current (amps) | Voltage (volts) | Time (min) | Observations |
|--|----------------|----------------------|----------------|-----------------|------------|--|
| <u>Run 1 - Static Test</u> | | | | | | |
| Ambient | Ambient | 10.0 | 0 | 0 | 0 | ----- |
| 140 | 140 | 10.2 | 10 | 0.2 | 1.5 | No change |
| 155 | 150 | 10.4 | 14 | 0.3 | 3.5 | No change |
| 260 | 220 | 10.8 | 21 | 0.4 | 5.5 | No change |
| 500 | 375 | 11.7 | 26.5 | 0.7 | 8.0 | External wire brown |
| 800 | 550 | 13.0 | 30 | 1.0 | 10.0 | Dense Smoke |
| 1050 | 620 | 19.3 | 34 | --- | 10.2 | Insulation Charred off-Central wire Glowing, then Melted |
| <u>Run 2 - Static Test</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | 0 | 0 | ----- |
| 193 | 158 | 11 | 34 | 1.1 | 0.5 | Charring |
| 288 | 350 | 11 | 34 | 1.35 | 1.0 | Ignition of Insulation |
| 330 | 360 | 13 | 34 | 1.48 | 1.5 | Burning continuing |
| 650 | 400 | 13 | 0 | ---- | 2.0 | Current Shut off, Wire Continued Burning |
| <u>Run 3 - Dynamic Test, Oxygen at 1L/min.</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | 0 | 0 | ----- |
| 93 | 100 | 10 | 34 | 1.2 | 0.2 | Discoloration |
| 205 | 150 | 10.5 | 34 | 1.2 | 0.5 | Heavy Smoke |
| 550 | 200 | ---- | -- | --- | --- | Rapid Ignition and Explosion |

b) Metal Test System

A new test system was constructed. This system was based on the original concept but modified to an all-metal system, the main difference being in the reaction vessel. A stainless steel pressure cooker was modified and adapted to function as a reaction vessel. The cover of the reaction vessel served as a blow-off valve in the event of explosions. A Lucite window was mounted in the bottom of the vessel to observe the phenomena occurring during heating. The test system is shown in Figure 2.4, and a detailed drawing of the reaction vessel is shown in Figure 2.5. All the experiments described below were carried out in this apparatus.

c) Three Wire Cables

Seven-inch lengths of cables consisting of three 24-gauge polyolefin heated wires, bound with sleeving, were tested under a pressure of $1/3$ atm of 100% O_2 . The tests were conducted under static and dynamic flow conditions for heated cables and for the same cables enmeshed in either treated or untreated sleeving. The results of these tests are shown in Tables 2.9 and 2.10.



- * TC#1 Internal Temp of Wire Bundle.
- * TC#2 External Temp of Wire Bundle.

Figure 2.4 Metal Test System

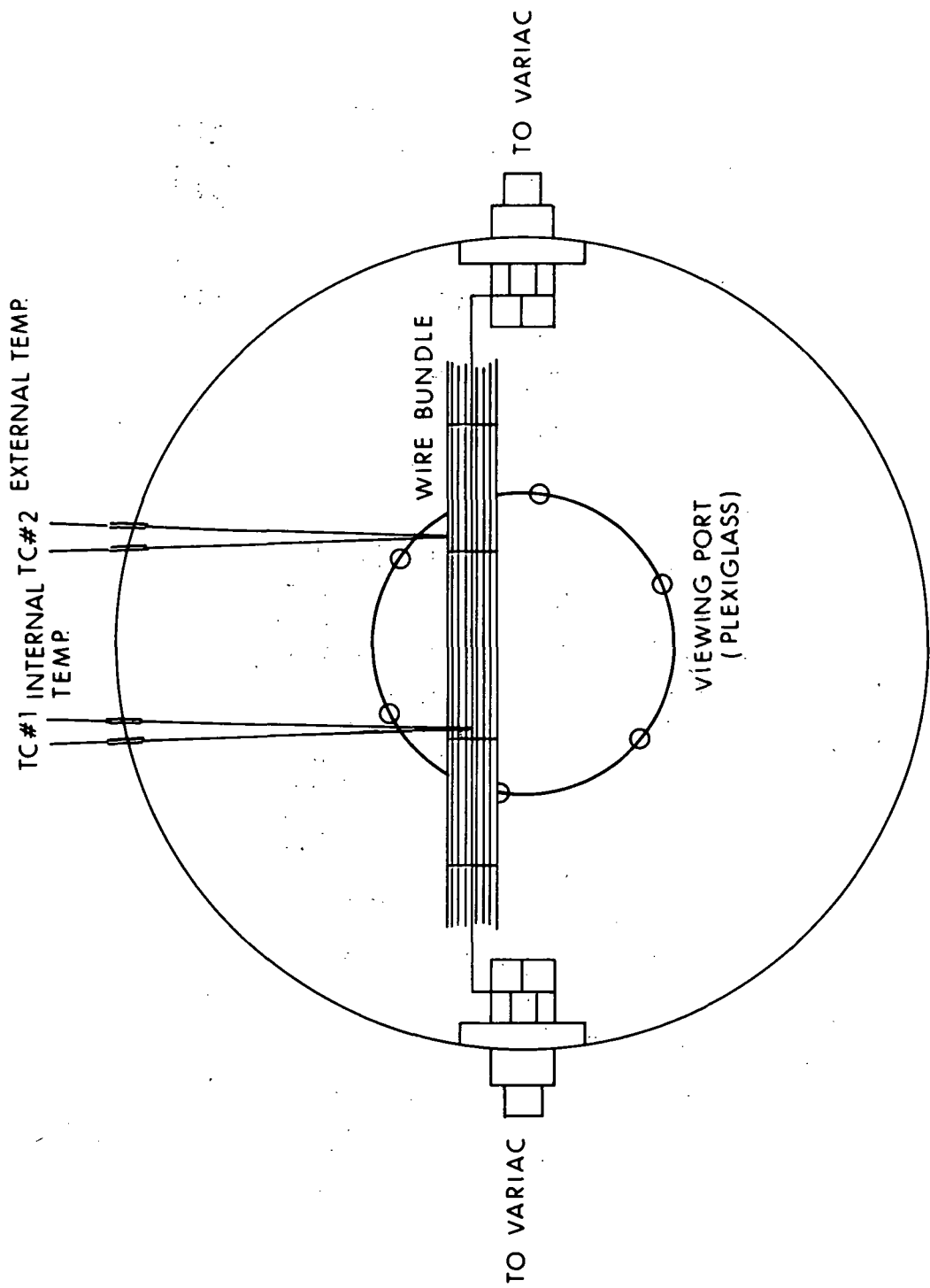


Figure 2.5 Stainless Steel Reaction Vessel (rear view).

TABLE 2.9

Bundles of Three Treated Wires with Untreated Sleeve.

| Internal Temp. (°F) | External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Volts | Time (min) | Observations |
|--|---------------------|----------------------|----------------|-------|------------|---------------------|
| <u>Run 1 - Dynamic System, Oxygen at 6 L/min at 1/3 atm.</u> | | | | | | |
| ----- | Ambient | 10 | 0 | | 0 | ----- |
| | 100 | 11 | 34 | | 0.5 | No change |
| | 125 | 11.5 | 34 | | 1.0 | Discoloration |
| | 130 | 17.0 | 34 | | 3.5 | Smoking |
| | 200 | 17.5 | 40 | | 4.0 | Heavy Smoking |
| | 250 | 18 | 40 | | 5.0 | Ignition-Burning |
| <u>Run 2 - Static System</u> | | | | | | |
| ----- | Ambient | 10 | 0 | | 0 | ----- |
| | 145 | 10 | 35 | | 0.5 | Discoloration |
| | 175 | 10.2 | 34 | | 1.0 | Brown Discoloration |
| | 250 | 11.1 | 34 | | 1.5 | Ignition-Explosion |
| <u>Run 3 - Static System</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | | 0 | ----- |
| 150 | 105 | 10 | 5 | | 4.5 | No change |
| 250 | 150 | 10 | 15.5 | | 10.5 | No change |
| 375 | 200 | 10 | 20.0 | | 14.5 | No change |
| 600 | 275 | 10.3 | 25.0 | | 19.0 | Brown Discoloration |
| 1000 | 325 | 11.2 | 30.0 | | 20.5 | Ignition-Explosion |
| <u>Run 4 - Static System</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | 0 | 0 | ----- |
| 200 | 150 | 10 | 25 | 0.5 | 1.0 | No change |
| 405 | 250 | 10 | 25 | 0.6 | 2.5 | No change |
| 500 | 300 | 10.2 | 25 | 0.65 | 4.5 | Brown Discoloration |
| 550 | 310 | 10.3 | 25 | 0.66 | 8.0 | Brown Discoloration |
| 675 | 390 | 10.3 | 30 | 0.90 | 8.5 | Smoking |
| 900 | 450 | 10.8 | 30 | 1.10 | 9.0 | Heavy Smoking |
| 1100 | --- | 11.3 | 30 | --- | 9.3 | Ignition-Explosion |

TABLE 2.9 (continued)

| Internal Temp. (°F) | External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Volts | Time (min) | Observations |
|--|---------------------|----------------------|----------------|-------|------------|--------------------------|
| <u>Run 5 - Dynamic System Oxygen at 3 L/min.</u> | | | | | | |
| ----- | Ambient | 10.0 | 0 | 0 | 0 | ----- |
| | 150 | 10.0 | 30 | 0.6 | 0.5 | No change |
| | 210 | 10.2 | 30 | 0.75 | 1.0 | No change |
| | 275 | 10.2 | 30 | 0.88 | 1.5 | Brown Discoloration |
| | 340 | 10.3 | 30 | 0.90 | 2.0 | Dark Brown Discoloration |
| | 350 | 10.3 | 30 | 1.10 | 2.5 | Dark Brown Discoloration |
| | 400 | 10.8 | 30 | 1.20 | 3.0 | Ignition-Explosion |

TABLE 2.10

Bundle of Three Treated Wires with Treated Sleeves.

| Internal Temp. (°F) | External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Voltage (volts) | Time (min) | Observations |
|---|---------------------|----------------------|----------------|-----------------|------------|-----------------------------------|
| <u>Run 1 - Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | | | |
| ----- | Ambient | 11 | 0 | 0 | 0 | ----- |
| | 150 | 11.5 | 20 | ---- | 1.5 | No change |
| | 160 | 11.8 | 20 | ---- | 2.5 | No change |
| | --- | 11.9 | 20 | ---- | 3.0 | Thermocouple moved |
| | --- | 12.2 | 20 | | 4.5 | No change |
| | | 12.5 | 30 | | 5.0 | No change |
| | | 13.0 | 30 | | 5.5 | Discoloration |
| | | 17.0 | 30 | | 6.5 | Smoking |
| | | 19.0 | 30 | | 7.0 | Heavy Smoke |
| | | ---- | 30 | | 7.5 | Ignition- Explosion |
| <u>Run 2 - Static System</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | 0 | 0 | ----- |
| 240 | 100 | 10 | 27.5 | 0.6 | 0.5 | No change |
| 575 | | 10.2 | 27.5 | 0.8 | 2.5 | Thermocouple moved, Discoloration |
| 640 | | 10.2 | 27.5 | 0.88 | 4.0 | Dark Brown - Light Smoke |
| 705 | | 10.6 | 27.5 | 0.95 | 7.0 | Heavy Smoke |
| 740 | | 10.9 | 27.5 | 1.0 | 11.0 | Heavy Smoke |
| 875 | | 11.0 | 30 | 1.20 | 13.0 | Voluminous Smoke |
| 975 | | ---- | 30 | ---- | 13.25 | Ignition - Explosion |

d) Bundle of Thirteen Wires

Bundles of 24-gauge polyolefin wires were constructed in a manner similar to that previously discussed. Both treated and untreated wires were tested. The treated wires had one coating of L-1483 retardant. All these runs were carried out under dynamic flow conditions. The results are shown in Tables 2.11 and 2.12.

e) Bundle of Thirteen Wires Sleeved

Bundles of 24-gauge polyolefin wires were constructed in a manner similar to that previously discussed; however, sleeving material was used to contain the wires. After the bundles had been prepared, Thermo-Fit tubing was shrunk on the bundle, forming a snug sleeve. Both treated and untreated wires were prepared in this manner. Wires were coated with one, two, and three coatings of L-1483 retardant. The results of untreated wires are shown in Tables 2.13 and 2.14.

f) Bundle of 43 Wires

A bundle of 43 polyolefin wires of 24-gauge was prepared and tested. These wires were not coated with L-1483. The results of one run of this bundle is shown in Table 2.15.

g) Bundle of 13 Wires with Copper Mesh Sleeves

Two bundles one with 13 and with 3, polyolefin wires of 24-gauge were prepared as before. A copper screening of 16 mesh was wrapped around each bundle forming a sleeve. The test results are shown in Table 2.16.

h) Teflon - Polyamide Insulated Wires

A bundle of 13 wires of 22-gauge Teflon-polyamide insulated wires was prepared and tested. The results are shown in Table 2.17.

Two bundles of 13 wires each of 24-gauge Teflon-polyamide insulated wires were prepared and tested. The results are shown in Table 2.18.

TABLE 2.11

Bundle of Thirteen Untreated Wires

| Internal Temp. (°F) | External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Voltage (volts) | Time (min) | Observations |
|---|---------------------|----------------------|----------------|-----------------|------------|--------------------------------------|
| <u>Run 1 - Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | | | |
| Ambient | Ambient | 10 | 0 | 0 | 0 | ----- |
| 325 | 200 | 10.5 | 34 | 0.8 | 0.5 | Smoking |
| 700 | 300 | 15.0 | 34 | --- | 1.0 | Heavy Smoke |
| 800 | --- | 17.0 | 34 | --- | 1.5 | Heavy Smoke Ignition - Burning |
| <u>Run 2 - Dynamic System Oxygen at 6 L/min at 1/3 atm.</u> | | | | | | |
| --- | Ambient | 9.1 | 0 | 0 | 0 | ----- |
| | 110 | 9.1 | 30 | --- | 0.5 | No change |
| | 140 | 9.2 | 30 | --- | 1.0 | No change |
| | 170 | 10.0 | 30 | --- | 1.5 | No change |
| | 200 | 11.0 | 30 | --- | 2.0 | No change |
| | 200 | 13.2 | 30 | --- | 2.5 | Discoloration Smoking |
| | --- | 15.0 | 30 | --- | 3.0 | Ignition - Explosion |

TABLE 2.12

Bundle of Thirteen Treated Wires

| External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Voltage (volts) | Time (min) | Observations |
|---|----------------------|----------------|-----------------|------------|---|
| <u>Run 1 - Dynamic System Oxygen at 6 L/min at 1/3 atm.</u> | | | | | |
| Ambient | 9.8 | 0 | 0 | 0 | ----- |
| 125 | 9.8 | 30 | 0.75 | 0.5 | No change |
| 160 | 9.8 | 30 | 0.80 | 1.0 | No change |
| 205 | 9.8 | 30 | 1.00 | 1.5 | No change |
| 290 | 11.2 | 30 | 1.25 | 2.0 | Discoloration |
| 350 | 13.2 | 30 | 1.50 | 2.5 | Smoking-Dark Brown Discol- oration |
| 400 | 15.0 | 30 | ---- | 3.0 | Ignition - Explosion |
| <u>Run 2 - Dynamic System Oxygen at 6 L/min at 1/3 atm.</u> | | | | | |
| Ambient | 10 | 0 | 0 | 0 | ----- |
| 105 | 10 | 30 | 0.75 | 0.5 | No change |
| 125 | 10.2 | 30 | 0.90 | 1.0 | No change |
| | 10.2 | 30 | 1.10 | 1.5 | Thermocouple moved, Discol- oration |
| | 10.2 | 30 | 1.20 | 2.0 | Smoking |
| | 10.5 | 30 | 1.35 | 2.5 | Heavy Smoking |
| | 11.0 | 30 | 1.50 | 3.0 | Ignition - Explosion |

TABLE 2.13

Bundle of Thirteen Untreated Wires with Sleeve

| External Temp. (°F) | | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|--|--------|-------------------------|-------------------|---------------|--------------------------|
| Thermo couple | Balco* | | | | |
| <u>Run 1 - Dynamic System, Oxygen at 3 L/min at 1/3 atm.</u> | | | | | |
| Ambient | | 9.2 | 0 | 0 | ----- |
| 125 | --- | 9.2 | 30 | 0.5 | No change |
| 150 | --- | 10 | 30 | 1.0 | No change |
| 180 | --- | 10.1 | 30 | 1.5 | No change |
| 200 | 180 | 10.2 | 30 | 2.0 | Discoloration |
| 225 | 260 | 10.5 | 30 | 2.5 | Smoking |
| --- | 290 | 11.8 | 30 | 3.0 | Charring - Smoking |
| --- | 300 | 12.5 | 30 | 3.5 | Heavy Smoking |
| --- | --- | ---- | 30 | 4.0 | Ignition - Explosion |
| <u>Run 2 - Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | | |
| Ambient | | 10 | 0 | 0 | ----- |
| 130 | | 10 | 30 | 0.5 | No change |
| 150 | | 10.1 | 30 | 1.0 | No change |
| 180 | | 10.3 | 30 | 1.5 | Smoking |
| 250 | | 10.5 | 30 | 2.0 | Brown Discol- oration |
| --- | | 11.0 | 30 | 2.5 | Heavy Smoking |
| 300 | | 12.0 | 30 | 3.0 | Ignition - Explosion |

* Balco wire was incorporated along the length of wire bundle and gave an average temperature; whereas thermocouple were fixed at mid-length of wires, where thermal effects were more intense.

TABLE 2.14

Bundle of Thirteen Treated Wires with Sleeve

| External Temp. (°F) | | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|---|--------|-------------------------|-------------------|---------------|---|
| Thermo couple | Balco* | | | | |
| <u>Run 1 - Dynamic Oxygen at 3 L/min at 1/3 atm.</u> | | | | | |
| Ambient | --- | 10.2 | 0 | 0 | ----- |
| 125 | --- | 10.2 | 30 | 0.5 | No change |
| 160 | --- | 10.2 | 30 | 1.0 | No change |
| 200 | --- | 10.2 | 30 | 1.5 | No change |
| 225 | --- | 10.2 | 30 | 2.0 | Discoloration |
| 275 | 230 | 10.3 | 30 | 2.5 | Smoking |
| 300 | 260 | 10.4 | 30 | 3.0 | Heavy Smoke |
| 340 | --- | 12.4 | 30 | 3.5 | Ignition-Fire |
| <u>Run 2 - Dynamic Oxygen at 3 L/min at 1/3 atm.</u> | | | | | |
| Ambient | | 10 | 0 | 0 | ----- |
| 110 | | 10 | 30 | 0.5 | No change |
| 150 | | 10 | 30 | 1.0 | Discoloration |
| 160 | | 10.4 | 30 | 1.5 | Sleeving Split Ignition-Spark- ing, burning |
| <u>Run 3 - Dynamic Oxygen at 3L/min at 1/3 atm.</u> <u>Three coatings of L-1483.</u> | | | | | |
| Ambient | | 10 | 0 | 0 | ----- |
| 100 | | 10 | 30 | 0.5 | No change |
| --- | | --- | 30 | 1.0 | No change |
| 180 | | 10.5 | 30 | 1.5 | Smoking |
| 300 | | 11.0 | 30 | 2.0 | Ignition - Burning |

* See comment at Table 2.13

TABLE 2.15

Bundle of 43 Untreated Wires with Sleeve

| External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|------------------------|-------------------------|-------------------|---------------|-----------------------|
| Ambient | 10 | 0 | 0 | ----- |
| 125 | 10 | 30 | 0.5 | No change |
| 160 | 10.5 | 30 | 3.0 | No change |
| 200 | 10.7 | 30 | 4.5 | Discoloration |
| 200 | 12.0 | 30 | 5.0 | Smoking |
| 200 | ---- | 30 | 5.5 | Ignition - Burning |

TABLE 2.16

Bundle of Untreated Wires With Copper Mesh Sleeves

| External Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|--|-------------------------|-------------------|---------------|--------------------|
| <u>Run 1 - Bundle of 13 Wires With Copper Screening as Sleeves</u> | | | | |
| <u>Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | |
| Ambient | 10 | 0 | 0 | ----- |
| 105 | 10 | 30 | 0.5 | No change |
| 150 | 10 | 30 | 1.0 | No change |
| 200 | 10 | 30 | 1.5 | Smoking |
| 275 | 10 | 30 | 2.0 | Heavy Smoking |
| 375 | 11.5 | 30 | 2.5 | Heavy Smoking |
| 450 | 15.0 | 30 | 3.0 | Ignition-Explosion |
| <u>Run 2 - Bundle of 3 Wires with Copper Braid As Sleeve</u> | | | | |
| <u>Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | |
| Ambient | 9.2 | 0 | 0 | ----- |
| 100 | 9.2 | 30 | 0.5 | Smoking |
| 130 | 9.8 | 30 | 1.0 | Heavy Smoking |
| 250 | 10.2 | 30 | 1.5 | Ignition-Explosion |

TABLE 2.17

Bundle of 13 Teflon-Polyamide Untreated Insulated Wire,
22 Guage.

| Internal Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|---|-------------------------|-------------------|---------------|----------------------------------|
| <u>Dynamic System Oxygen at 3 L/min at 1/3 atm.</u> | | | | |
| Ambient | 10 | 0 | 0 | ----- |
| 150 | 10 | 0 | 0.5 | No change |
| 250 | 10.3 | 30 | 2.0 | No change |
| 300 | 10.6 | 30 | 3.0 | No change |
| 350 | 11.0 | 30 | 5.5 | No change |
| 360 | 11.0 | 30 | 6.5 | No change |
| 360 | 11.0 | 30 | 8.0 | No visible effect on wire. |

TABLE 2.18

Bundle of 13 Teflon-Polyamide Insulated Wire,
24 Guage, Untreated.

| Internal Temp. (°F) | Pressure (in. of Hg) | Current (amps) | Time (min) | Observations |
|---|-------------------------|-------------------|---------------|---|
| <u>Run 1 - Dynamic System 3 L/min at 1/3 atm.</u> | | | | |
| Ambient | 10.5 | 0 | 0 | No change |
| 200 | 10.5 | 30 | 0.5 | No change |
| 350 | 10.5 | 30 | 1.0 | No change |
| 425 | 10.5 | 30 | 1.5 | No change |
| 475 | 11 | 30 | 2.0 | Discoloration |
| 550 | 13 | 30 | 2.5 | Insulation Melted and exposed wire No burning or explosion |
| <u>Run 2 - Dynamic System 3 L/min at 1/3 atm.</u> | | | | |
| Ambient | 10 | 0 | 0 | ----- |
| 210 | 11 | 30 | 0.5 | No change |
| 300 | 11 | 30 | 1.0 | No change |
| 400 | 10.3 | 30 | 1.5 | No change |
| 450 | 11.5 | 30 | 2.0 | No change |
| 500 | 13 | 30 | 2.5 | Wire exposed and shorted, No burn- ing or explosion. |

APPENDIX A

PYROLYSIS AND TOXICITY OF TEFLON-INSULATED WIRES

Experimental Procedure

Electrical wire AWG 22 with Teflon insulation was cut in 1-inch lengths. Each sample was flame-sealed in a small pyrex ampoule. These were then baked for 10 minutes each at 600°F, 700°F, 800°F, 900°F, 1000°F, 1,100°F, and 1,200°F. The latter sample was lost through rupture of the ampoule due to the high pressure exerted by the products of pyrolysis.

Each ampoule was then introduced into a Bendix Time-of-Flight Mass Spectrometer and analyzed semiquantitatively. The results are shown in Table A.1.

TABLE A.1

| Sample | Pyrolized at T, (°F) | Mass Spectrometer Analyses |
|--------|----------------------|---|
| 1" TFE | 600 | No significant findings |
| 1" TFE | 700 | No significant findings |
| 1" TFE | 800 | No significant findings |
| 1" TFE | 900 | Products of pyrolysis showing. A more accurate Mass Spectrometric analysis should be made. (See Note 1) |
| 1" TFE | 1,000 | Same products of pyrolysis showing in 2 to 3 times the abundance at 900 degree F. (See Note 1) |
| 1" TFE | 1,100 | Same products of pyrolysis showing in about 2 times the abundance at 1,000° F. (See Note 1) |
| 1" TFE | 1,200 | No analysis was possible, as the products of pyrolysis were in such abundance that the ampoule ruptured in the baking oven. |

Note 1. Some of the more abundant products of this pyrolytic degradation of the TFE insulation are given in the order of the mass spectrometric peak amplitudes shown:

SiF_3^+ , showing an amplitude larger than that of Nitrogen in atmospheric air. If the partial pressure of this ion were known, and if it were equal to the partial pressure of Nitrogen in atmospheric air (it is believed to be higher), the percentage of this ion would be at least 89%, (Ref. 1). This ion forms from the SiF_4 molecule, which, in turn is formed by reaction between either F_2 or HF and the Silicon Dioxide of the pyrex ampoules. The F_2 originates from the pyrolytic decomposition of the TFE, or the HF originates from reaction between the F_2 from the TFE and H_2 made available within the experimental ampoule. (Ref. 2) In either case the experimental evidence points to the availability of a large quantity of F, originating obviously from the TFE. The threshold set by the American Conference On Industrial Hygiene is 3 parts per million, or 2 milligrams of Hydrofluoric Acid per cubic meter of air, for one minute exposure.

$C_3F_5^+$, showing one of the many possible degradation products of TFE. This ion would react with moisture of organic living tissue (i. e., mucous membrane of the human respiratory tract), to form noxious Fluorinated compounds. As it contains an un-even number of Carbon atoms, it would not produce Fluoroacetic Acid. It has been found that Fluorinated Hydrocarbons containing an even number of Carbon Atoms may -upon ingestion- form Fluoroacetic acid, the toxicity of which is very high. Of this Fluoroacetic Acid, the Handbook on Industrial Hygiene and Toxicology, Volume II, Interscience, 1962, states on page 1774: "Fluoroacetic Acid has extraordinary toxicity, having lethal effects in some species at 50 micrograms per 50 kilograms" (of body weight) ... "Symptoms are acute convulsive or cardiac effects, appearing after variable latent period".

$C_4F_5^+$, showing another of many possible degradation products of TFE. This ion appears in an abundance of approximately one half of that of the above radical, $C_3F_5^+$, and will lead to the formation of Fluoroacetic Acid, upon ingestion, as per the notation made immediately above.

$C_4F_9^+$, showing another of the many possible degradation products of TFE. This ion appears in an abundance of approximately one half of that of the ion immediately above, $C_4F_5^+$. In as much as it contains an even number of Carbon atoms, it will contribute to the formation of Fluoroacetic Acid, on ingestion, with the added lethal biological effects noted above.

C_2F_4 , Perfluorethelene, showing an abundance similar to that of Oxygen in atmospheric air, i. e. 20% by volume, on the assumption, as stated above, of comparable partial pressures. This, again, being a fluorinated compound having an even number of Carbon atoms, would presumably lead to the formation of Fluoroacetic Acid on ingestion, and, hence, add to the lethality associated with this compound.

Similar information is given by the DuPont Company (Ref. 3) in their Bulletin A-28708, on page 5, Table I, entitled "Weight loss and ventilation recommended for Teflon fabricated resins above 450°F". In this Table, the maximum temperature given is 800°F, whereas in our sampling and baking of Teflon wires we indicated (Table A-1) that at 900°F and above, the Mass spectrometer showed significant products of pyrolysis.

The DuPont Table gives a weight loss of 0.15% at 800°F for Teflon and a recommended air ventilation of 325 cu ft/min/lb of resin for safety. A quick calculation of these data shows:

Weight of products of pyrolysis of Teflon (wire insulation) at 800°F:

$$\frac{0.15 \text{ gms}}{\text{gm hr}} = \frac{0.0025 \text{ gms}}{\text{gm min.}}$$

for which an air ventilation is recommended of

$$\frac{325 \text{ cu ft}}{\text{min lb (of resin)}} \quad \text{or} \quad \frac{0.7 \text{ cu ft}}{\text{min gm (of resin)}}$$

Taking an average molecular weight of the products of pyrolysis (see Mass Spectrometer Analysis, above) as 135, the potentially toxic concentration becomes:

$$\frac{2.5 \text{ mg}}{19.8 \text{ liters min gm}}, \quad \text{or} \quad \frac{0.126 \text{ mg}}{\text{L min gm}}$$

or

$$22.8 \text{ pp m (If average Mol Wt} = 135, \\ \text{then } 1 \text{ mg/L} = 181.1 \text{ pp m).}$$

The possibility that the even-numbered products of Teflon pyrolysis will react with moisture to form Fluoroacetic Acid has been indicated above. The Threshold Limit Value for this poison is given as 0.1 mg/cubic meter (see Reference 1, page 1801).

If we assume that the even-numbered radicals of Table A-1 constitute one half of the total radicals produced, the build up of the poison, in one minute, could reach a value of over ten times the Threshold Limit Value. This estimate is obtained on considering that the free volume of the Command Module is of the order of one cubic meter.

It is apparent that specific tests with live animals should be undertaken to confirm or deny the possibility of this toxic hazard stemming from the use of Teflon.

Finally, quoted below are the conclusions on this problem reached by the Occupational Medical Services of MIT in a bulletin revised December, 1961, entitled "Health Hazards Involved in the Use of Teflon".

"Teflon is a polymerized fluorocarbon which has many applications because of its physical, chemical, and electrical properties. For example, it is used in the form of tubing or gaskets for its chemical inertness, and as a coating for wire because of its excellent insulating properties; in the form of an aerosol spray it is used as a lubricant. MIT laboratories are using Teflon in significant amounts and many questions about its toxicity have come to the Occupational Medical Service.

"TOXICITY: Animal studies have shown that at ordinary temperatures, Teflon does not cause skin irritation, nor does it produce ill effects when taken by mouth in small quantities. Experience in industry confirms this observation.

Teflon, when heated, decomposes to products (gasses and fumes) which, when inhaled, may cause toxic symptoms. This decomposition starts about 400°F (204°C); at this temperature the weight loss is only 0.0002% per hour and does not increase significantly until the temperature reaches 680°F (360°C). The products evolved include Hydrogen Fluoride and fully Fluorinated Hydrocarbons, one of which, Octafluoroisobutylene, is reported to be more toxic than Phosgene.

"In serious cases, involving a large exposure to Teflon decomposition products, signs and symptoms, similar to the acute state of severe pneumonia, may occur suddenly or after a delay of several hours. In the event of such an exposure, followed by coughing, chest pain, and shortness of breath, prompt medical attention should be sought.

The most common effect of exposure to heated Teflon is "polyfume fever", which is similar to "metal fume fever", and is characterized by chills and fever occurring several hours after exposure. Symptoms disappear without special treatment within 36 to 48 hours. Inhalation of finely divided unheated Teflon has been reported to produce these same symptoms.

"SOURCE OF EXPOSURE: Since Teflon is potentially harmful at elevated temperatures, any heating process should be regarded as a source of exposure. Soldering of Teflon-coated wires is one possible source. In the Occupational Medical Service laboratory we have demonstrated that substantial amounts of fume may be produced by accidental burn-out of Teflon-coated wires in electrical systems. This could prove hazardous if such wires were used in improperly fused systems in confined spaces. Machining processes such as turning, cutting, grinding, or sawing may produce sufficient heat to cause thermal breakdown or considerable airborne dust and should be regarded as a source of exposure. If castings are to be made with Teflon a potential hazard undoubtedly exists.

"The manufacturers of Teflon state that contaminated cigarettes, cigars, and pipe tobacco may produce ill effects. Contamination of smoking materials by Teflon therefore must be prevented.

PRECAUTIONS: If it is found necessary to machine Teflon frequently or to heat it for a long period of time above 400°F (204°C) the operation should be performed under a suitable exhaust hood or local exhaust system. Use of coolants is advisable in high speed machining. If advice on ventilation is needed, call the Occupational Medical Service. Ext. 2596".

References:

- (1) J. H. Beynon, "Mass Spectrometry and its Applications to Organic Chemistry", Elsevier Publishing Company, 1960. Chapter 10.
- (2) Ibid. Section 9.17
- (3) E. I. DuPont De Nemours and Company, Inc., Plastics Department, "Handling and Use of "Teflon" Fluorocarbon Resins at High Temperatures", Bulletin A-28708.

E-1713

DISTRIBUTION LIST

Internal

| | | |
|-----------------------|------------------------|------------------------|
| R. Alonso | W. Heintz | John Miller |
| J. Arnow (Lincoln) | E. Hickey | J. Nevins |
| R. Battin | D. Hoag | J. Nugent |
| P. Bowditch | A. Hopkins | E. Olsson |
| A. Boyce | F. Houston | C. Parker |
| R. Boyd | L. B. Johnson | J. Rhode |
| E. Copps | B. Katz | W. Schmidt |
| R. Crisp | A. Koso | E. Schwarm |
| W. Crocker | M. Kramer | N. Sears |
| G. Cushman | W. Kupfer | D. Shansky |
| J. Dahlen | A. Laats | W. Shotwell (MIT/ACSP) |
| E. Duggan | D. Ladd | T. Shuck |
| K. Dunipace (MIT/AMR) | A. La Pointe | J. Sitomer |
| R. Euvrard | J. Larsen | W. Stameris |
| J. B. Feldman | L. Larson | N. Thacher |
| S. Felix (MIT/S&ID) | J. Lawrence (MIT/GAEC) | R. Therrien |
| J. Flanders | T. M. Lawton (MIT/MSC) | W. Toth |
| J. Fleming | R. Magee | M. Trageser |
| L. Gediman | G. Mayo | R. Weatherbee |
| D. Grief | J. McNeil | L. Wilk |
| Eldon Hall | R. McKern | R. Woodbury |
| D. Hanley | R. Mudgett | W. Wrigley |
| | | Apollo Library (2) |
| | | MIT/IL Library (6) |

External

(ref. PP1-64; April 8, 1964)

| | |
|--|------|
| P. Ebersole (NASA/MSC) | (2) |
| W. Rhine (NASA/RASPO) | (1) |
| L. Holdridge (NAA S&ID/MIT) | (1) |
| T. Heueremann (GAEC/MIT) | (1) |
| AC Spark Plug | (10) |
| Kollsman | (10) |
| Raytheon | (10) |
| Major W. Delaney (AFSC/MIT) | (1) |
| NAA RASPO: National Aeronautics and Space Administration Resident Apollo Spacecraft Program Office North American Aviation, Inc. Space and Information Systems Division 12214 Lakewood Boulevard Downey, California | (1) |
| FO: National Aeronautics and Space Administration, MSC Florida Operations, Box MS Cocoa Beach, Florida 32931 Attn: Mr. B. P. Brown | (3) |
| HDQ: NASA Headquarters 600 Independence Ave., SW Washington 25, D. C. 20546 Attn: MAP-2 | (6) |
| AMES National Aeronautics and Space Administration Ames Research Center Moffett Field, California Attn: Library | (2) |
| LEWIS: National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio Attn: Library | (2) |
| FRC: National Aeronautics and Space Administration Flight Research Center Edwards AFB, California Attn: Research Library | (1) |
| LRC: National Aeronautics and Space Administration Langley Research Center Langley AFB, Virginia Attn: Mr. A. T. Mattson | (2) |
| GSFC: National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland Attn: Manned Flight Support Office Code 512 | (2) |

MSFC: National Aeronautics and Space Administration (2)
 George C. Marshall Space Flight Center
 Huntsville, Alabama
 Attn: R-SA

ERC: National Aeronautics and Space Administration (1)
 Electronics Research Center
 575 Technology Square
 Cambridge, Massachusetts
 Attn: R. Hayes/A. Colella

GAEC: Grumman Aircraft Engineering Corporation (1)
 Bethpage, Long Island, New York
 Attn: Mr. A. Whitaker

NAA: North American Aviation, Inc. (1)
 Space and Information Systems Division
 12214 Lakewood Boulevard
 Downey, California
 Attn: Mr. R. Berry

GAEC RASPO: National Aeronautics and Space Administration (1)
 Resident Apollo Spacecraft Program Officer
 Grumman Aircraft Engineering Corporation
 Bethpage, L. I., New York

ACSP RASPO: National Aeronautics and Space Administration (1)
 Resident Apollo Spacecraft Program Officer
 Dept. 32-31
 AC Spark Plug Division of General Motors
 Milwaukee 1, Wisconsin
 Attn: Mr. W. Swingle

WSMR: National Aeronautics and Space Administration (2)
 Post Office Drawer MM
 Las Cruces, New Mexico
 Attn: BW 44

MSC: National Aeronautics and Space Administration (45)
 Manned Spacecraft Center
 Apollo Document Control Group
 Houston 1, Texas 77058

Mr. H. Peterson (1)
 Bureau of Naval Weapons
 c/o Raytheon Company
 Foundry Avenue
 Waltham, Massachusetts

Queens Material Quality Section (1)
 c/o Kollsman Instrument Corp.
 Building A 80-08 45th Avenue
 Elmhurst, New York 11373
 Attn: Mr. S. Schwartz

Mr. H. Anschuetz (1)
 USAF Contract Management District
 AC Spark Plug Division of General Motors
 Milwaukee, Wisconsin 53201