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# INVESTIGATION OF TOXIC PROPERTIES OF MATERIALS USED IN SPACE VEHICLES

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BIOMEDICAL LABORATORY 6570th AEROSPACE MEDICAL RESEARCH LABORATORIES AEROSPACE MEDICAL DIVISION AIR FORCE SYSTEMS COMMAND WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Contract Monitors: Capt. Alan B. Cooper, USAF, MC, and Dr. N. A. Poulos Project No. 6302, Task No. 630203



(Prepared under Contract No. AF 33(657)-8029 by W. J. Olewinski, G. Rapier, T. K. Slawecki, and H. Warner General Electric Company, Missile and Space Division Philadelphia 1, Pennsylvania)

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### FOREWORD

This study was initiated by the Toxic Hazards Branch, Physiology Division, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories. The research was conducted by the Missile and Space Division of the General Electric Company, Philadelphia, Pennsylvania, under Contract No. AF 33(657)-8029. The principal investigators for the General Electric Company, under the project leadership of Mr. William J. Olewinski, were Mr. Gordon Rapier, Dr. Tadeusz Slawecki, and Mr. Harold Warner. Capt. Alan B. Cooper, USAF, MC, and Dr. N.A. Poulos, task engineers, were the contract monitors for the Biomedical Laboratory. The work was performed in support of Project No. 6302, "Toxic Hazards of Propellants and Materials," Task No. 630203, "Identification of Toxic Materials." This study was started in March 1962 and completed in January 1963.

The authors acknowledge the invaluable assistance of Mr. Robert Downing and Mr. George Schacher of the General Engineering Laboratory, General Electric Company, for their part in the irradiated materials evaluation. Acknowledgement is also given to the Boeing Company, McDonnell Aircraft Corporation, and North American Aviation Corporation for providing spacecraft materials data.

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### ABSTRACT

The objectives of this program were: (1) to compile lists of materials presently used or proposed for use in spacecraft — specifically, the Apollo, Mercury, Gemini, and Dyna-Soar programs—and to assess the possible toxic properties and breakdown products of these materials under thermal and other anticipated stresses and (2) to evaluate methods for the detection and identification of space cabin contaminants for the purpose of compiling the requirements, methods, and specifications on available instrumentation. These in turn can serve as the basis for development of a compact kit for detection of toxic off-gassing from materials employed in space vehicles.

For other than short duration missions, monitoring instrumentation must be capable of the detection and identification of a wide variety of toxic contaminants, some of which may not have been anticipated. A highly sensitive multiple gas detector, either directly or in combination with a trace gas separation and concentration technique, appears to be a desirable approach. Many of the comments on gases and vapors also apply to particulate type contaminants.

### PUBLICATION REVIEW

This technical documentary report is approved.

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JOS. M. QUASHNOCK Colonel, USAF, MC Chief, Biomedical Laboratory

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### INTRODUCTION

In a spacecraft with a closed and recirculated atmospheric environment, gradual contamination of the environment by the accumulation of toxic gases, vapors and dust particles may be expected under normal operating conditions unless suitable control equipment is provided. This contaminant build-up problem is particularly complex for long duration manned space missions.

In order to establish an atmosphere control regime, it is essential to identify those materials projected for use in spacecraft which are potentially capable of evolving toxic substances; to learn more about the characteristics of these evolved toxic substances; to devise methods of eliminating or reducing the accumulation of these substances to prescribed safe levels in closed environments; and to detect whether in fact prescribed safe levels are being violated.

Listed below are several methods envisioned for control of toxic contaminants in spacecraft atmospheres:

- Employment of devices for removal of the contaminants per se as they evolve.
- Construction of spacecraft using materials which are not toxic per se and which do not outgas toxic contaminants.
- Limitation of the total amount of potentially toxic materials used in spacecraft construction, i.e., permit contamination within safe limits.

No doubt, for the present and immediate future, all three methods will be employed. But it is obvious that to insure the reliability of these methods, there is an urgent requirement to obtain more information regarding the materials planned for use in spacecraft as well as knowledge regarding the toxic properties of these materials and instrumentation for their detection.

Thus the objectives of this study were twofold and subdivided into two phases. In Phase I, the objective was to determine as many materials as possible which were being used or considered for use in spacecraft construction and to delineate the outgassing and/or other decomposition products under expected environmental conditions. Having appraised the contaminants which might evolve from the various materials, the Phase II objective was to compile methods for the detection and identification of these contaminants as a basis for the development of a compact toxic instrumentation kit for spacecraft applications. It should be noted that a well designed manned spacecraft will have equipment on-board to control the concentration of atmosphere contaminants. This of course does not preclude a build-up of contaminants due either to partial or total failure of this equipment or the evolution of an unexpected toxic constituent which the equipment cannot control. Thus, the requirements, methods and specifications for suitable instrumentation must proceed on the basis of potential contaminants based on planned spacecraft materials without regard to the efficiency of the contaminant removal equipment.

### SOURCES OF CONTAMINANTS

The contaminants which may accumulate in the atmosphere of a manned spacecraft are derived from two principal sources: (a) biological and (b) materials and equipment.

Since there is information presently available pertaining to the toxicity of the various substances derived from human metabolic and waste products, it was decided only to summarize these substances and to concentrate the Phase I efforts on evaluations of material derived substances.

### BIOLOGICALLY DERIVED CONTAMINANTS

Most substances which are evolved by man and animals as products of their metabolism are predictable. Table 1 summarizes the substances which have been reported. These are expected to vary appreciably, depending on vehicle type, length of mission, and contaminant disposal techniques employed. The rates of output may vary considerably as a function of such factors as diet, temperature and pressure. Although the list seems impressive, perhaps only a relatively small number of human waste products appearing in Table 1 demand serious consideration. Those that are considered toxic under normal conditions and evolve from feces and flatus as well as from urine are indicated in Table 2. The selection criteria, Table 3, was based on the classification proposed by Hodge and Sterner (Ref. 1).

### MATERIAL DERIVED CONTAMINANTS

Materials used in spacecraft construction present the other prime source of potential toxic substances. A wide variety of materials (metals, plastics, rubber, finishes, adhesives, etc.) have been used and are anticipated for use in manned spacecraft.

### Metals

In general, because of their high vaporization temperatures, metals are considered to be relatively non-toxic except when contained in the spacecraft in the form of dust or vapor. Table 4, based on data in Appendixes A through C and G.E. manned space vehicle studies, lists the metals expected to be found within a typical spacecraft. These metals, generally found in combination with each other, or as oxides, can be considered as the basic materials from which the structure and equipment will be manufactured.

These metals, with the exceptions noted in Table 4, are considered to present no toxic hazard for use in a spacecraft environment. They generally have vaporization temperatures well above expected ambient atmosphere temperatures. Oxidation of these materials appears to pose no problem since the oxides are particularly stable and will not outgas in the temperature/pressure environment expected.

### Plastics

Plastic compounds of various types will be found in manned spacecraft. These materials, fiberglass, phenolics, plexiglas, styrofoam and teflon, will be used as trim,

# HUMAN WASTE PRODUCTS (1)

### Feces and Flatus

Indole	Methyl mercaptan	Amino acids
Skatole	Nitrogen	Ammonia
Paracresol	Hydrogen	Mucus
proprionic acid	Proteoses	Starch granules
Hydrogen sulfide	Peptones	Fats and fatty
Methane	Peptides	acid

### Urine

Water Solids Inorganic Salts Cations - Sodium, potassium, calcium, magnesium, ammonium Anions - Chloride, phosphate, sulfate, cabonate Organic Compounds - Urea, uric acid, hippuric acid, creatinine, indican, oxalic acid, allantoin, purine bases, phenols, organic sulfates Inorganic Compounds - Inorganic sulfates, sulfur dioxide

Expired Air

Oxygen	Isoprene	Furan
Carbon Dioxide	Methanol	Propionaldehyde
Water Vapor	Ethanol	Dimethyl sulfide
Acetone	Methyl furan	Isovaleraldehyde
Acetaldehyde	Carbon monoxide $(2)$	-

### Sweat

Inorganic Salts
Cations - Sodium, potassium, calcium, magnesium, copper
manganese, iron
Anions - Chloride, sulfate
Organic Compounds - Lactic acid, glucose, urea, uric acid,
ammonia, creatinine, amino acids, phenol, histamine,
fatty acid esters.

- (1) Condensed from Ref. 2 through 5.
- (2) R. E. Forster, Per. Comm., Univ. of Penna., 1963.

### TABLE 2\*

Substance	MAC in ppm
Feces & Flatus**	
Ammonia Carbon Dioxide Hydrogen Sulfide Methyl Mercaptan	100 5,000 20 50
Urine	
Acetone Phenols Sulfur Dioxide	400 - 1,000 5 5 - 10
Expired Air	
Acetaldehyde Carbon Dioxide Ethyl Alcohol Methyl Alcohol Carbon Monoxide	200 5,000 1,000 200 100
Sweat	
Ammonia	100

### TOXIC GASES AND VAPORS: HUMAN WASTE PRODUCTS

\*Condensed from Table 1 - those compounds with MAC's under

10,000.
\*\*Skatole, indole, paracresol and proprionic acid are toxic
although not listed in the TLV tables.

### TABLE 3

### TOXICITY CLASSIFICATION

Toxicity	MAC in ppm
Extremely toxic Highly toxic Moderately toxic Slightly toxic Practically non-toxic Relatively harmless	$ \begin{array}{r} 10\\ 10 - 100\\ 10 - 1,000\\ 1,000 - 10,000\\ 10,000 - 100,000\\ > 100,000 \end{array} $

### EXPECTED METALLIC SPACECRAFT MATERIALS

<u>Metal</u>		Threshold Limit Value* Mg./M <sup>3</sup>
Aluminum	]-	
Antimony**	0.5	
Beryllium**	0.002	
Cadmium**	0.1	(as oxide)
Chromium**	0.1	(as Cr0 <sub>3</sub> )
Copper**		(Salts are known to be toxic)
Gold		
Iron	~~	
Lead**	0.2	
Magnesium**	15.0	(as oxide)
Manganese**	5.0	
Mercury**	0.1	
Molybdenum**	5.0	(Soluble compounds)
Molybdenum**	15.0	(Insoluble Compounds)
Nickel		
Selenium**	0.1	
Silver	~-	
Tellurium**	0.1	
Titanium	~-	
Zinc**	5.0	(As oxide)

\*Threshold Limit Values for 1962. 24th Annual Meeting of the American Conference of Governmental Industrial Hygienists.

\*\*Known to be toxic (Ref. 6)

insulation, instrument faces, light structure, ducting, controls, switches, seats, food containers, instrument panel faces, and electrical insulation.

The majority of the high molecular weight plastic compounds are inert and nontoxic. However, frequently some unreacted material is present which may outgas under certain conditions of temperature and pressure. In addition, plasticizers such as tricresyl phosphate and camphor are toxic and may be volatilized if the material is heated.

### Rubber

Rubber will be used in the spacecraft in many forms as seals, insulation, padding, shock mounts, survival gear, elastic, control handles, etc.

Natural and synthetic rubbers are non-toxic at normal temperatures. Natural rubber latex, however, contains ammonia which is released when heated. Neoprene latex contains partly polymerized chloroprene which gives off a strong odor. Finished rubber contains fillers, plasticizers, accelerators, anti-oxidants, retarders, vulcanizing agents and pigments. While most of these are innocuous, some might require additional investigation for long term use in a closed environment.

### Finishes

All finishes such as paint, varnishes, enamels and lacquers contain toxic solvents (benzene, naphtha). Materials in the precured state are also hazardous.

### Adhesives

Cements most probably will be carried in the spacecraft for making minor repairs. These cements, made from plastic or rubber, contain volatile solvents such as naphtha and toluene which can result in a toxic hazard during use and curing. Here again, concentration will be important and must be investigated with respect to long term continuous exposure.

### Natural Fibers

Natural fibers such as cotton, flax and wool have had a toxic effect when inhaled in quantity (Ref. 6). It would appear, however, that the fibers in the manufactured product would not cause any irritation.

### Lubricants

Petroleum products such as those which would be used for lubricating rotating machinery, contain relatively high percentages of naphthenes and aromatic hydrocarbons. While these components require relatively high concentration before becoming dangerous, it is conceivable that the increase in volatility of the substance caused by heat or friction could, over a period of time, cause at least unpleasant odors and visible fumes. Hydraulic fluids are known to be volatile and contain toxic compounds. The high operating pressures of these fluids (1,000 to 3,000 psi) are such that even minute leaks could create a toxic hazard by aerosolization.

### **Refrigerants and Heat Transfer Fluids**

These fluids, notably freon, ethylene glycol, and alcohol can be expected to create toxicity problems if released into the controlled environment.

### Fire Extinguishants

Carbon dioxide is expected to be the principal agent utilized for extinguishing internal spacecraft fires; however, other agents such as foams, dry chemicals (for example, sodium bicarbonate) and vaporizing liquids such as halogenated hydrocarbons are also available. Virtually all of the presently available agents are potential hazards when introduced into a closed environment.

Table 5 (Ref. 7) lists various fire extinguishing compounds, with the approximate concentrations at which they are lethal after 15 minutes of exposure. Since many of these compounds have an anesthetic effect before becoming lethal, the Table also gives the exposure times that the two vapor conditions take to produce anesthesia.

### **Contaminant Generation**

Mechanical, thermal, and other stresses applied to materials may produce gases, vapors, or airborne particulate matter. Smoke, dust and liquid droplets are examples of particulate matter. The following are the stresses or mechanisms which are considered as significant to the generation of contaminants in spacecraft. Note that the total quantity of contaminants generated may be limited by either the ambient environment as in evaporation and condensation or the amount of the material available as in thermal decomposition.

### **Elevated Temperatures**

An increase in temperature, such as would accompany a short circuit or fire, would most certainly produce toxic fumes, gases and smoke from a number of organic and inorganic materials found within the spacecraft. Only general statements can be made regarding the thermal degradation products and decomposition temperatures of many of the materials, in particular the plastics where the pyrolytic products depend to a great extent upon the degree of polymerization and the cure and additives used. Many polymers undergo slow self-polymerization even at ambient temperatures, so that different decomposition temperatures may be obtained from various samples of the same polymer.

### Evaporation

Low ambient pressures affect materials in two ways: by evaporation of the material or a volatile component of the material, and/or by removal of the layer of adsorbed gas on the surface of the material. Sublimation and evaporation of materials are enhanced by the absence of an atmosphere in that molecules leaving the surface of the material are not reflected by collisions back to the surface.

The evaporation rate of a pure material can be calculated from kinetic theory (Ref. 8) as follows:

# APPROXIMATE LETHAL CONCENTRATIONS OF VARIOUS FIRE EXTINGUISHING AGENTS (REF. 7) (15 Minute Exposure)

	Natu	ural Vapor		Pyro	lyzed Vapo	*.
Agent	mg/1	шđđ	min**	mg/1	mqq	min**
Bromotrifluoromethane Carbon tetrafluoride Bromochlorodifluoroethane 1,2-dibromotetrafluoroethane Carbon dioxide Ferfluoromethylcyclohexane Ethyl bromide Dibromodifluoromethane Chlorobromomethane 1,2-dibromo-2-chlorotrifluoroethane Carbon tetrachloride Methyl bromide Methyl iodide Methyl iodide	2200 2220 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 22200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 200 2000000	800,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,0000 1481,000 1481,000 1481,000 1481,000 1481,000 1481,0	๚๗๚๚๚๛๛๚๚๛๛๛๛	3220 3220 1200 117 117 252 110 252 20 350 350 350	14,000 895,000 1,650 15,500 16,500 16,500 12,000 12,000 60,500 60,500	۵۹۱۳ ۳۰۳۵۵ ۳

\*Pyrolyzed in iron tube at 800°C to simulate a typical fire condition.

\*\*Anesthesia time.

$$G = \frac{P}{17.14} \sqrt{\frac{M}{T}}$$

where

 $G = evaporation rate, g/(cm^2)$  (sec)

M = molecular weight

 $T = absolute temperature ^{O}K$ 

P = vapor pressure, mm Hg at temperature T.

It is not expected that the rate of evaporation of most metals will be a significant problem if the temperature is below 300°F. However, cadmium, zinc and mercury will evaporate appreciably below this temperature. Magnesium would appear to be a marginal material at this temperature.

Plastics, on the other hand, are more complex than metals because they contain a variety of ingredients. Although the basic polymer of the plastic is not likely to have a high enough vapor pressure to cause significant loss of material, some of the other ingredients may. In particular, plasticizers used in many plastics have relatively high vapor pressures; however, loss of plasticizer from a plastic is dependent on the diffusion rate of the plasticizer to the surface, which may be slower than the evaporation rate of the pure material would indicate.

For a given material, the saturated vapor phase that is in equilibrium with the surface of the solid or liquid exerts a finite pressure; this pressure, possessed by all liquids and solids, is the vapor pressure of the material. Moreover, if a material is a mixture of several ingredients, each ingredient exerts its own finite vapor pressure. The ingredients of such a material would, therefore, be expected to diffuse and escape from the materials at different rates until such time that the vapor phase of each ingredient in the material is in equilibrium with the vapor of the same ingredient in the ambient atmosphere. This, of course, assumes that the total pressure of the atmosphere is greater than that of the vapor phase within the ingredient. If the vapor pressure were higher than the total pressure, a condition of boiling would be obtained if a liquid phase were present.

For total pressures of 5 to 7 psia as would be expected in a manned spacecraft atmosphere, the steady-state total concentration of a specific contaminant resulting from the outgassing of a particular material is independent of the quantity of material available, and depends only upon an equilibrium condition between the vapor phase of the contaminant in the material and that in the environment. Table 6 lists the vapor pressure at approximate ambient temperatures for various toxic substances together with a comparison of the corresponding concentration at maximum permissible ACGIH limits. Note that if the rate of generation is low or the spacecraft not leaktight (a normal condition), the concentrations noted for equilibrium conditions may never be reached.

### Recondensation

As noted above, whenever the vapor pressure of a substance exceeds the partial pressure of that substance in its ambient, molecules escape from the material into the

### VAPOR PRESSURE OF TOXIC SUBSTANCES

Substance	Formula	<u>T(1)</u>	Vapor Pressure(2	) <u>TLV</u> (3)
Acetaldehyde Acetic Anhydride Acrolein Allyl Alcohol Allyl Chloride Amyl Acetate Aniline Benzyl Chloride Butyl Acetate Butylamine Carbon Disulfide Carbon Tetrachloride Chloroform Chloropicrin Chloroprene Cresol Cyclohexanol Cyclohexanol Cyclohexanone o-Dichlorobenzene p-Dichlorobenzene 1,1 Dichloroethane 1,2 Dichloroethylene	$C_{2H40}$ $C_{4H60}$ $C_{3H4}$ $C_{3H4}$ $C_{3H4}$ $C_{3H4}$ $C_{3H4}$ $C_{2H47}$ $C_{7H1}$ $C_{7H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1}$ $C_{2H1$	20.2 3343754250000980250700840 33754252835378518099991.	1,000,000 13,200 526,000 52,600 526,000 13,200 1,300 26,300 26,300 26,300 526,000 132,000 1,300 1,300 132,000 1,300 132,000 1,300 132,000 1,300 132,000 1,200 1,300 1,300 1,300 1,300 1,300 1,300 1,300 1,300 1,200 1,300 1,300 1,200 1,300 1,300 1,300 1,300 1,300 1,300 1,300 1,300 1,200 1,300 1,200 1,300 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,200 1,	200. 5. 20. 20. 20. 20. 20. 20. 20. 20
methane Diethylamine Dimethylaniline Dioxane Ethyl Acetate Ethyl Accylate Ethyl Alcohol Ethylbenzene Ethyl Bromide Ethyl Formate Ethylene Chlorohydrin Ethylene Dibromide Furfural Alcohol Heptane Hexane	$CC1_{2}F_{2}$ $C4H_{11}N$ $C8H_{10}2$ $C4H_{80}2$ $C4H_{80}2$ $C4H_{80}2$ $C2H_{80}2$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$ $C2H_{10}r$	42.4 38.0 29.5 27.0 26.9 21.0 34.9 21.1 30.3 21.7 31.8 321.7 31.8 31.6	13,200 526,000 1,300 52,600 132,000 132,000 13,200 13,200 13,200 13,200 13,200 13,200 13,200 26,300 1,300 52,600 263,000	1,000. 25. 100. 400. 25. 1,000. 200. 200. 100. 5. 10. 50. 500. 500.

Temperature in <sup>o</sup>C.
 Vapor pressure in ppm (by volume) at temperature T and 760 mm Hg total pressure.
 ACGIH Threshold Limit Values for 1962 in ppm.

TABLE 6 (Cont'd)

Substance	Formula	$\underline{T(1)}$	Vapor Pressure (2	) $\underline{TLV}(3)$
Hexanone Hydrogen Cyanide Hydrogen Fluoride Iodine Mesityl oxide Methyl Acetate Methyl Accylate Methyl Alcohol Methyl Alcohol Methylcyclohexane Methyl Formate a-Methyl Styrene Methylene Chloride Nitroethane Nitrogen Dioxide Nitromethane 2-Nitropropane Octane Pentane Pentanone Phenol Phosphorus trichloride Propyl Acetate Propyl Alcohol Propylene oxide	$\begin{array}{c} C_{6}H_{12}O\\ HCN\\ HF\\ I_{2}\\ C_{6}H_{10}O\\ C_{3}H_{6}O_{2}\\ C_{4}H_{6}O\\ C_{3}H_{6}O_{2}\\ C_{1}H_{4}O\\ C_{7}H_{14}O\\ C_{2}H_{4}O\\ C_{7}H_{14}O\\ C_{9}H_{10}\\ C_{9}H_{10}O\\ C_{13}H_{10}O\\ C_{13}H_{18}O\\ C_{5}H_{10}O\\ C_{5}H_{6}O\\ PC I_{3}O_{2}O\\ C_{3}H_{6}O\\ C_{5}H_{6}O\\ PC I_{3}O_{2}O\\ C_{3}H_{6}O\\ C_{6}O\\ C_{$	38.9 9.7 38.9 19.7 28.0 28.2 22.1 22.2 3474.0 22.2 3474.0 22.2 351.0 35.0 28.5 18.1 08.35 39.1 28.5 18.1 08.35 34.1 28.5 34.2 28.5 35.5 18.1 28.5 35.5 35.5 35.5 35.5 35.5 35.5 35.5 3	$\begin{array}{c} 13,200\\ 1,000,000\\ 1,000,000\\ 1,300\\ 263,000\\ 132,000\\ 132,000\\ 52,600\\ 1,000,000\\ 13,200\\ 52,600\\ 1,000,000\\ 52,600\\ 26,300\\ 26,300\\ 26,300\\ 1,000,000\\ 52,600\\ 1,300\\ 132,000\\ 52,600\\ 1,300\\ 132,000\\ 52,600\\ 1,300\\ 132,000\\ 52,600\\ 1,300\\ 132,000\\ 52,600\\ 1,300\\ 132,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,600\\ 1,000,000\\ 52,000\\ 52,000\\ 52,000\\ 1,000,000\\ 52,000\\ 52,000\\ 1,000,000\\ 52,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 1,000\\ 52,000\\ 52,000\\ 1,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52,000\\ 52$	$ \begin{array}{c} 100.\\ 10.\\ 3.\\ 0.1\\ 25.\\ 200.\\ 10.\\ 200.\\ 500.\\ 100.\\ 500.\\ 100.\\ 500.\\ 100.\\ 5.\\ 100.\\ 25.\\ 500.\\ 1,000.\\ 200.\\ 5.\\ 0.5\\ 200.\\ 400.\\ 100 \end{array} $
Pyridine 1,1,2,2, Tetrachlor-	C5H5N	24.8	26,300	5.
oethane Toluene Trichloroethylene Xylene	$C_{2}H_{2}C_{14}$ $C_{7}H_{8}$ $C_{2}HC_{13}$ $C_{8}H_{10}$	33.0 31.8 31.4 32.1	1,300 52,600 132,000 13,200	5. 200. 100. 200.

Temperature in <sup>O</sup>C.
 Vapor pressure in ppm (by volume) at temperature T and 760 mm Hg total pressure.
 ACGIH Threshold Limit Values for 1962 in ppm.

ambient. As the vapor pressure is a function of the temperature, if a volatile material is heated, molecules can escape. However, if the temperature of the ambient is lower, then the molecules will recombine and become airborne particulate matter. In general, particles so produced are quite small with few larger than 0.1 microns in diameter.

An example of this mechanism is the production of many airborne particles during an electrical discharge (e.g., motor brushes, relay contacts opening), when the electrode material is evaporated and recondenses into minute particles. Many particles are also formed by this process during the smoking of cigarettes.

### Mechanical Generation

This mechanism includes any action, either natural or man-made, by which particles are mechanically produced and distributed into the air, such as the rubbing and consequent abrasion of two surfaces (such as cloth on cloth, causing lint). The particles generated by this mechanism are physically torn from the parent material and dispersed into the air. Liquid sprays are also considered in this category. The particles so produced are generally sized from 0.1 to 100 microns.

In determining the ease of production, the mechanical properties of the material, such as crystal structure, density, and bonding forces, are important for the solids; viscosity and density are the more important factors for the liquids.

### **Conversion of Gases**

The formation of particles from the chemical change of a gas brought about by oxidation has been demonstrated in the laboratory and in the free atmosphere. The importance of this mechanism has only recently been realized. By chemical change, gases in the air may form other compounds which tend to be solid or liquid under normal pressure and temperatures. This process occurs for example in the smogs of Los Angeles. An excellent example of this type of production is the conversion of SO<sub>2</sub> gas into SO<sub>3</sub> by reaction with ozone and the subsequent formation of H<sub>2</sub>SO<sub>4</sub> droplets when water vapor reacts with SO<sub>3</sub>. By this process, very small droplets in the range from  $10^{-7}$  to 5 x  $10^{-7}$  cm in diameter are produced.

### Radiation

In discussing radiation damage to materials, it is convenient to consider three broad material classifications: metals and alloys; organic materials such as polymers, greases, and paint vehicles; and inorganic materials such as glasses or ceramics.

<u>Metals and Alloys</u>. In general, metals and alloys are relatively resistant to radiation damage. For the most part, only fast neutrons are effective in producing any damage in metals. Electrons or beta particles, having low mass, do not transfer sufficient kinetic energy to induce damage and gamma radiation, and being effective only in producing ionization, do not affect metal properties. <u>Organic Materials.</u> Organic materials are notably susceptible to radiation damage. Unlike metals, there is a definite molecular structure in organics which may be destroyed and is not capable of healing through processes akin to annealing. It has been shown repeatedly that radiation-induced damage is dependent on the total energy absorbed, and sometimes on the radiation intensity, but rarely, if ever, dependent on the type or source of radiation.

The types of damage produced in organics by irradiation are summarized as follows: Polymers may be produced by chain scission and subsequent interaction of active bond sites; graft polymers may be produced; long-chain polymers (rubber, polyethylene, etc.) may be cross-linked to form rigid three-dimensional networks; polymers may be degraded to reduce molecular weight, increase vapor pressure, decrease viscosity, and decrease mechanical strength. Crystallinity in polymers such as nylon, polyethylene and teflon is destroyed by radiation.

<u>Inorganic Materials</u>. Inorganic materials are generally resistant to radiation damage, as are metals. This is undoubtedly due to the nature of ionic rather than covalent bonding inherent in organic structures.

### IRRADIATED MATERIALS EVALUATION

Although decomposition of materials to the point of changing their physical properties occurs at radiation doses many times higher than those lethal to man, outgassing of toxic gases may possibly take place at doses several orders of magnitude less. During long-term missions, such as space station or planetary probe operations, the spacecraft crew may take refuge in specially shielded chambers when high intensity, high energy, short-term radiation is imminent. Thus the normal spacecraft living quarters could easily be irradiated with doses high enough to cause toxic outgassing from materials.

### Procedure

As previously noted, organic materials tend to have the least radiation resistance in terms of physical properties. Among the organics, the plastics and elastomers show a marked susceptibility to radiation. In general, plastics are more resistant to radiation damage than are elastomers. Plastics may be exposed to  $10^4$ to  $10^8$  roentgens irradiation before a physical change appears, while elastomers can only absorb dosages of up to  $10^0$  roentgens before being damaged, (Ref. 9). Bovey (Ref. 10) has shown that when subjected to high dosage radiation, some plastics (notably polymethyl methacrylate) will evolve H<sub>2</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>,O<sub>2</sub> and other hydrocarbons.

In general, irradiation effects studies have been concerned with performance degradation, reduction in mechanical or other properties, outgassing, etc., at high dose rates, i.e., limit conditions. No data was found concerning the effect of minimum of threshold dose rates. Therefore, it was concluded that an exploratory evaluation should be made of the effects of radiation on selected organic materials at dose rates considerably lower than those which had been reported in the literature. A dosage of 6,000 roentgens at a rate of 50 roentgens per minute was selected. This dosage is one order of magnitude higher than man's  $LD_{90}$ .

Table 7 lists the four materials together with helium and paraffin samples, which were evaluated as part of the study program. Since Kel-F is a fluorinated compound, its container was lined with a high-purity paraffin. A sample of paraffin alone was also included in order to evaluate, separately, the radiation effects on the paraffin. The sample container used is shown in Figure 1. This glass type container is used routinely for gas analysis at General Electric. The sample material is introduced into the sample volume through the seal-off tube. Examination of the larger glass tube affixed to the top of the sample volume will reveal a "break-off" seal approximately 20 percent of the distance up from the top of the sample volume. The sample volume is evacuated through the seal-off tube following introduction of the sample material. The volume is then recompressed to the desired pressure with the specified gas or gas mixture. While maintaining these conditions the seal-off tube is heated and pinched-off to effect a seal.

When it is desired to connect the sample volume into the analytical instrumentation complex, a thoroughly washed and cleansed steel plug is placed in the tube above the break-off seal. The entire container is connected to the instrumentation manifold by means of the 12-30 taper and the volume above the break-off seal evacuated. The steel slug is then lifted magnetically and allowed to fall, fracturing the break-off seal and thereby admitting the gas mixture, in the sample volume, into the instrumentation manifold.

The glass containers were prepared by a thorough cleaning with a solution of potassium dichromate and sulfuric acid followed by distilled water rinses and overnight oven drying. The sample materials were shredded, where necessary, and introduced into the sample volume through the seal-off tube. The container was filled to 7 psia (the expected total atmosphere pressure in a manned spacecraft) with an inert atmosphere of helium. Helium was used in these exploratory tests to preclude masking of the offgassing products by high oxygen and nitrogen partial pressure concentrations. It should be noted that the use of helium in these exploratory tests thus did not permit recombinations of some of the offgassed products with oxygen or nitrogen.

Gamma irradiation and subsequent gas analysis was accomplished at General Electric's 15,000 curie cobalt-60 facility in Schenectady, New York. Figure 2 is typical of the test set-up for the irradiation of the samples. The samples were arranged in a suitable rack at a specified distance from the radiation source. In the lower center of the picture is the ion chamber for measuring the radiation dose rate. Immediately after the irradiation, gas analyses were run on the samples using a GE high resolution (250 unity mass) mass spectrometer.

### Results

In Table 7 are the data from the mass spectrometer analysis of the material samples selected. Data from both the control and irradiated samples are presented. Quantities given are in mol %, (percentage concentration). The total sample volume after expansion into the mass spectrometer was 250 cc. This volume, with the pressures as noted, and with the concentration levels indicated, can be used to compute approximately the actual quantity of gas generated.

TABLE 7. MASS SPECTROMETER ANALYSIS OF IRRADIATED SAMPLES (IN MOL %)

	Helium	Hypalon-	20	Silicone	Rubber	Thiokol		Paraffin	Kel F	
CAS	Control	Control	irradiated	Control	irradiated	Control	irradiated	irradiated	Control	irradiated
Helium	6.99	97.3	96.9	6.99	6*66	99.4	99.4	6.66	1.99	99.3
Water Vapor			0.01		0.01	0.05	0.2		0.01	0,01
Methane				0.07	0.01					
Nitrogen	0.002	2.0	2.5		10.0	0.3	0.3	0.01	0.6	0.5
Oxygen		0.4	0.5			0.1	0.1	0.05	0.2	0.09
Argon		0.01	0.02			0.005			0.005	0.002
Carbon Dioxide			10.0	0.04	0.03	0.04	0.03	100.0	100.0	0.007
Sulfur Dioxide		0.2	0.003						0.0005	
Carbon Tetrachloride		0.1	0.05							
Ethylene						0.02				
Hydrocarbons								0.006	0.005	0.017
Sample Pressure mm/250 cc	125	117	115	129	127	118	119	129	135	130

Note: Helium irradiation and paraffin control were not considered necessary.



Figure 1. Sample Container





Offgassing of significance, after irradiation, occurred in only two instances. One — carbon dioxide from Kel-F, 70 ppm — is of relatively little importance; the other — chlorinated hydrocarbons from Kel-F, 170 ppm — is of importance. Kel-F is employed as electrical insulating material under elevated thermal environments; MAC's among chlorinated hydrocarbons range as low as 25 ppm.

However, the volume of the sample container was about 60 ml, half of which was occupied by loosely packed sample materials either in powder form or as finely cut up pieces. Assuming a packing factor of 0.5, the total volume occupied by gas was about 37.5 ml. Assuming further the maximum dimensions of sample pieces to be 1 cm x 1/2 cm x 1/10 cm, 12.5 cc of sample has an approximate area of 325 sq. cms. Thus, a minimum of 325 sq. cm. of sample participates in the offgassing process into a volume of 37.5 cc, a condition much more severe by several orders of magnitude than would be encountered in the interior of a manned space vehicle.

From the foregoing paragraph, it might be assumed that off-gassing from irradiated materials is not a problem. However, it would be presumptuous to make this assumption without a full scale study, involving irradiation of many more materials, in both oxygen and nitrogen atmospheres.

### THERMAL DEGRADATION

Materials proposed for use in spacecraft may be divided into two broad classes, metals and non-metals. From the point of view of thermal degradation, metals may be considered as inert under expected thermal environmental conditions for manned spacecraft and therefore may be omitted from further discussions.

Among the non-metals, few natural products such as latex, natural fibers, and leather are likely to find spacecraft applications. Other non-metallics such as ceramics, inorganic coatings, and glasses are well known for their inertness even at elevated temperatures and for this reason should not cause any concern. The main source of possible toxic contaminants are the various polymeric materials together with the additives, solvents, plasticizers and catalytic agents used in their manufacture.

The tentative materials for manned spacecraft, Appendices A, B, and C, contain large numbers of such polymers. Their use is quite varied — from structural members to potting compounds, electrical wire insulation, coatings, enamels. varnishes, items of clothing, utensils, and a host of other applications too numerous to mention.

### Polymer Breakdown Mechanism

Degradation of such polymeric materials takes place continuously, even at ordinary temperatures. With temperature rise the degradation is accelerated. The mechanism of such degradation is quite varied and is also temperature dependent. At lower temperatures, loss of volatiles usually occurs first. This may be coupled with very slow additional cross-linking and perhaps some oxidation at or near the surfaces exposed to an oxidizing atmosphere such as air. This process is commonly referred to as aging. At low temperatures, most large polymer molecules are relatively stable. Thus during aging very little evolution of low-molecular weight gases may be expected to take place. Any gases evolved during aging are usually low boiling point solvents and water vapor. The mechanism of gas evolution under such conditions is essentially that of diffusion of gases through solids and through any pores and gas pockets that may be present.

At higher temperatures, in addition to above processes, depolymerization of the polymers into the constituent monomers may also take place. Their evolution will depend primarily on their vapor pressure and to some extent on the diffusion.

At still higher temperatures the monomeric substances may undergo partial decomposition, chemical reactions may take place between such fragments and the parent polymer, the products of the condensation reactions may be evolved, and oxidation may take place at a much higher rate. Increasing the temperature still further, the polymer may break down in random fashion into larger molecular forms which may further decompose or react with each other to form a whole spectrum of chemical compounds.

At very high temperatures some polymers carbonize with almost complete loss of hydrogen and other groups. Other polymers decompose completely without leaving residues.

The exact mechanism of polymer breakdown depends primarily on the molecular structure (Ref. 12). For instance, the breakdown of simple vinyl polymers takes place in accordance with various mechanisms as follows:

- a. Breakdown of the chain into a molecular spectrum having from one to about 50 carbons. An example of such a polymer is polymethylene. After an initial step of degradation has taken place, resulting in the formation of some free radicals, the main process of degradation depends on a transfer of the free-radical activity through hydrogen abstraction.
- b. If some of the hydrogen in the polymer chain is replaced by some other atoms or radicals the displacement of hydrogen by intramolecular abstraction at the site of scission becomes more or less limited. As a result some scission reactions cause free radical formation which can unzip into monomers, can react further with the polymer or other radicals. In case of vinyl polymers the monomer yield is quite high. Table 8 (Ref. 12) lists the half-life ( $T_h$ ) and monomer yields of a number of polymers pyrolized in a vacuum at temperatures below 600°C. Polystyrene, which is really a polymethylene in which one of the hydrogen atoms is replaced by a phenyl group, yields on pyrolysis below 600°C, 40% monomer.
- c. Breakdown by a mechanism yielding almost 100 percent monomer.

Polymers, in which one of the hydrogens on alternate carbons is substituted by a methyl radical and the other hydrogen by some other, still larger group such as phenyl or ester, decompose into free radicals which in turn unzip into monomers. This action is due to steric hindrance which prevents intramolecular hydrogen transfer by blocking of scission sites by these large groups. Methyl methacrylate and alpha – methyl styrene polymers belong to this category. These polymers when heated at temperatures to  $500^{\circ}$ C, decompose almost completely into monomers. In case of polytetrafluoroethylene (Teflon), which also yields monomers on thermal decomposition, steric hindrance is not involved. The carbon-fluorine bond is much stronger than the carbon-hydrogen bond, the result of which is a chain scission into free radicals which unzip into monomers.

### TABLE 8

	the second s	
Polymer	т <sub>h</sub>	Monomer *
Polytetrafluoroethylene (teflon) Polymethylene Polytrifluoroethylene Polybutadiene Branched Polyethylene Polypropylene Polychlorotrifluoroethylene(Kel-F) Poly - A-deuterostyrene Polystyrene Poly-a-deuterostyrene Poly-m-methylstyrene Polyisobutylene Poly(methyl acrylate) Poly(methyl methacrylate) Poly-a-methylstyrene	°C 509 412 407 407 387 380 372 362 358 358 358 358 3558 3558 3558 3558 35	>95 Trace 0 2 Trace 0.2 27 39 40 68 45 20 Trace 91 >95

HALF-LIFE (7	$\Gamma_{h}$ )	ANI	) MONO	DMER	YIELD	IN	THE
PYROLYS	SÏŚ.	OF	SOME	POLY	MERS		

\* In weight percent of total volatilized part.

d. Breakdown into large chain fragments and small molecules, not particularly related to the structural unit of the polymer. A typical example is methyl methacrylate, which when pyrolyzed at temperatures below 500<sup>o</sup>C yields mainly carbon dioxide and methyl alcohol. Other examples are vinyl chloride, vinyl fluoride, vinylidene fluoride, and acrylo-nitrile polymers. The chloride, the fluoride, and the nitrile polymers decompose to yield, in addition to large polymer fragments, HCl, HF, and HCN, respectively.

Only a very crude estimation of off-gassing from inspection of chemical composition is possible in terms of the kinds of molecules that could possibly be generated during the breakdown of polymers. Thus polymers containing chlorine may evolve hydrogen chloride and possibly, phosgene. Polymers containing nitrogen may evolve ammonia and various oxides of nitrogen. In general, hydrocarbon type polymers will give off various hydrocarbon products of degradation such as methane, ethylene, and longer chain hydrocarbons. For ready reference, Appendix E lists the chemical composition of the more important polymers likely to be used in manned spacecraft.

### Test Method

Studies of the thermal degradation of polymers are performed by pyrolyzing representative samples. Reliable and reproducible measurements are obtained only through careful control in sampling and pyrolysis, and high precision in detection of the weight loss and in the separation and identification of the volatile constituents. The slow process of diffusion of degradation products through the viscous mass of the decomposing polymer must be considered in the sampling step and in the choice of pyrolysis technique. As the pyrolysis temperature is increased, viscosity is lowered but reaction between the pyrolysis products may be accelerated. Under most conditions, thin films give best results. The type of information desired, whether it is identification of a polymer or the analysis of the gaseous products, determines whether pyrolysis should be performed on a hot filament or in a tube furnace. Extensive use has been made of trapping the volatile decomposition products. However, for determination of the composition of the volatiles, gas chromatography, mass spectrometry, or their combination have proven to be the most powerful methods.

For screening purposes the thermogravimetric analysis (TGA) has found almost universal acceptance. In this method weight loss, continuously measured versus time or temperature, provides a rapid method for following the degradation of polymers over a wide temperature range. Detailed degradation kinetics and mechanism investigations can be made conveniently by thermogravimetry, since conditions for vigorous isothermal degradation studies can be quickly selected. Hot-filament pyrolysis is very useful in identification of pyrolysis products. This method can be applied in conjunction with mass or infrared spectroscopy or gas chromatography.

### **Relative Stability of Polymers**

For polymers that vaporize almost completely on pyrolysis at temperatures below  $600^{\circ}$ C, the relative stability may be established by heating them under exactly the same conditions for a specified period of time and comparing the amount of sample volatilized. Figures 3 and 4 (Ref. 11) show experimental data obtained during vacuum pyrolysis.

Each circle represents a separate experiment of 30 minutes duration at the indicated temperature. The curves, with the exception of vinyl chloride, vinylidene fluoride, and acrylo-nitrile polymers, have generally the same shape, and the relative thermal stability of the represented polymers is quite obvious. However, another convenient method of representing relative thermal stability is to compare characteristic temperatures  $(T_h)$  which is the temperature in degrees C at which 50% of the original polymer weight is lost. A series of polymers arranged in the order of their decreasing thermal stability, based on  $T_h$  values, is shown in Table 8.

Polymers such as polyvinyl chloride, polyacrylonitrile, and polyvinylidene fluoride, which develop crosslinking during pyrolysis, or polytrivinylbenzene, which is highly crosslinked initially, do not vaporize completely. In such cases a more appropriate scale of comparison would be the amount of residue remaining after pyrolysis and the extent of carbonization of the residue.



Figure 3. Relative Thermal Stability of Polymers at Lower Temperatures



Figure 4. Relative Thermal Stability of High-Temperature Polymers

### Breakdown Products

Madorsky and Straus (Ref. 12) performed an extensive study of polymer degradation at temperatures up to 1200<sup>o</sup>C. The study included identification of the constituents of degradation products, determinations of fraction of the samples volatilized at various temperatures, and obtaining the rates of degradation of the polymers under investigation. The representative polymers studied were:

- a. Polyester (Vibrin 136A), consisting of equal parts by weight of maleic anhydride and triallyl cyanurate, with tertiary butyl perbenzoate as the curing agent.
- b. Epoxy (Epon 1310) which is a condensation product of epichlorohydrin with a polyphenol containing 3 to 4 phenolic groups per molecule and having a molecular weight of 200 per epoxide group. Boron trifluoride was used as the curing agent.
- c. Phenolic (phenol-formaldehyde resin).
- d. Silicone with methyl and phenyl groups attached to silicon atoms in a silicon-oxygen chain.
- e. Polyvinylidene fluoride polymerized by  $\gamma$ -radiation.
- f. Polytrivinylbenzene.
- g. Polyacrylonitrile.
- h. Polymethylene.
- i. Copolymers of styrene with divinylbenzene and trivinylbenzene.

Tables 9 through 14 illustrate typical results. Note that the component quantities vary as a function of pyrolysis temperature.

In still another comprehensive study of thermal degradation of polymers, Grundfest (6) (Ref. 13) reported results shown in Tables 16 and 17. Table 15 identifies the polymers investigated.

In June 1958, the Pyrolysis Task Group of the ASTM E-14 Committee on Mass Spectrometry prepared an annotated bibliography on the subjects of pyrolysis and depolymerization. This bibliography is reproduced herein for reference purposes in Appendix F. A more recent and more inclusive bibliography on the subject of degradation of materials was also prepared and is included as Appendix G.

One factor common to past studies of the thermal degradation of polymers is the relatively high temperatures involved as compared to those existing within a manned spacecraft. No data at ambient temperatures and in the presence of high oxygen concentration atmospheres was discovered. The high temperature data is significant, however, in revealing the probable toxic contaminants which may be generated at lower temperatures even though the rate of generation may be such that no problem is anticipated.

### PROPOSED SPACECRAFT MATERIALS

### Current Programs

Listed in the Appendix are specific materials which have been indicated for potential use in the following spacecraft:

- Apollo Appendix A
- Mercury Appendix B
- Dynasoar (X-20) Appendix C

The information obtained was qualitative in nature rather than quantitative. With quantitative information, it would have been possible to assess the probable rate of accumulation of the toxic products of these materials. Unfortunately, quantitative materials data have not been compiled by any of the sources contacted. Moreover, the data as available were incomplete and no assurances could be given that all of the materials listed would be finally approved for use.

### TABLE 9

	Tempe	erature	e of P	yrolys	sis, °(	;
	500 <sup>0</sup>		80	00	1200	) <sup>0</sup>
Polymer	Vol*	M**	Vo1	M	<b>V</b> ol	M
	96		<i>9</i> 6		<b>%</b>	
Vibrin Epoxy Phenolic Poly(vinylidene fluoride) Polytrivinylbenzene Polymethylene Polystyrene***	83 75 28 76 55 100	73 146 76 29 162 583	89 86 47 85 68 98 100	49 71 24 29 57 230 141**	93 87 48 90 63 98 <b>-</b>	39 36 41 29 40 30 <b></b>

### THERMAL DEGRADATION OF POLYMERS IN A VACUUM AT VARIOUS TEMPERATURES (REF. 12)

\*Vol - stands for volatilization in percent of sample.

\*\*M - stands for average molecular weight of all volatiles.

\*\*\*Figures for polystyrene are based on results of pyrolysis at 850°C.

Component *	Vibrin	Epoxy	Phenolic
	%	76	70
H <sub>2</sub>	1.3	2.1	2.8
со	7.2	25.9	2.2
co2	29.4	1.8	1.2
сн <sub>4</sub>	3.4	4.3	4.9
C₂H₂	0.1	2.5	1.9
с <sub>2</sub> н <sub>4</sub>	14.8	3.0	1.6
с <sub>3</sub> н <sub>4</sub>	0.1	0.4	0.3
с <sub>3<sup>н</sup>б</sub>	1.6	0.1	0.8
с <sub>4</sub> н <sub>б</sub>	1.4	0.2	0.1
с <sub>5</sub> н <sub>б</sub>	1.3	0.6	0.9
с <sub>6н</sub>	4.7	8.1	9.0
с <sub>7</sub> н <sub>8</sub>	0.1	0.1	1.5
V <sub>pyr</sub>	38.2	50.9	72.8
Total	100.0	100.0	100.0
Volatilization, % of Sample	93	87	48

### ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS OF THERMOSET PLASTICS IN A VACUUM AT 1200° (Ref. 12)

\* Amounts of components are given in weight percent of total volatilized part.

### ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS OF POLYTRIVINYLBENZENE IN A VACUUM (Ref. 12)

Component*	Temperature	of Pyrolysis	
	500° C	800° C	1200 <sup>0</sup> C
	%	%	K
H <sub>2</sub>	0.1	2.1	3.3
СН4	1.7	5.0	4.8
C <sub>2</sub> H <sub>2</sub>			3.3
С <sub>2</sub> н <sub>4</sub>	1.8	0.7	3.3
°₂ <sup>н</sup> 6	1.5	0.9	0.1
с <sub>3</sub> н <sub>4</sub>	0.1	0.1	
с <sub>3</sub> н <sub>б</sub>	1.0	1.4	0.1
с <sub>3</sub> н <sub>8</sub>	0.8	0.3	0.1
с <sub>4</sub> н <sub>8</sub>	0.8	0.2	0.1
с <sub>5</sub> н <sub>10</sub>	0.1	0.1	
с <sub>6</sub> н <sub>6</sub>	0.1	0.2	4.0
с <sub>7</sub> н <sub>8</sub>	0.2	0.4	0.3
с <sub>8</sub> н <sub>8</sub>	0.1	0.1	
C8H10	1.2	0.8	
С <sub>9</sub> н <sub>10</sub>	0.8	0.2	
C9H12	2.4	1.0	~
C <sub>10</sub> H <sub>14</sub>	1.9	0.4	
C <sub>11</sub> H <sub>16</sub>	0.6	0.1	
V <sub>pyr</sub> **'	84.8	86.0	80.6
Total	100.0	100.0	100.0
% of Sample	55	68	63

\* Amounts of components are given in weight percent of total volatilized part.

\*\*Pyrolysis products not volatile at room temperature.

Component*	Temperatur	e of Pyrolysis	
Component*	500° C	800° C	1200° C
	%	%	%
H <sub>2</sub>		0.1	1.5
Сн <sub>4</sub>		0.4	5.8
C <sub>2</sub> H <sub>2</sub>		0.1	4.9
°₂ <sup>н</sup> ₄	0.1	2.7	40.1
С <sub>2</sub> н <sub>б</sub>		0.1	0.7
с <sub>3</sub> н <sub>4</sub>		0.1	5.6
° <sub>3<sup>H</sup>6</sub>	0.1	1.9	11.4
с <sub>3</sub> н <sub>8</sub>	0.1	0.2	0.5
C <sub>4</sub> H <sub>4</sub>			2.9
с <sub>4</sub> н <sub>б</sub>	0.1	0.5	7.7
C <sub>4</sub> H <sub>8</sub>	0.1	1.7	2.7
C <sub>4</sub> H <sub>1O</sub>	0.1	0.1	
°5 <sup>H</sup> 6			1.1
с <sub>5</sub> н <sub>8</sub>	<b></b>	0.5	2.0
с <sub>бнб</sub>		0.1	1.6
° <sub>6</sub> н <sub>10</sub>	0.2	0.4	
с <sub>6н15</sub>	0.4	1.2	
c <sub>6</sub> H <sub>14</sub>	0.2	0.3	
C <sub>7</sub> H <sub>12</sub>	0.2	0.3	0.5
с <sub>7</sub> н <sub>14</sub>	0.7	1.2	
с <sub>7</sub> н <sub>16</sub>	0.4	0.2	

### ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS OF POLYMETHYLENE IN A VACUUM (Ref. 12)

\*Amounts of components are given in weight percent of total volatilized part.

### TABLE 12 (Continued)

### ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS OF POLYMETHYLENE IN A VACUUM (Ref. 12)

	Temperature	of Pyrolysis	
Component*	500° C	800° c	1200 <sup>0</sup> C
	Ķ	76	%
с <sub>8</sub> н <sub>16</sub>		0.4	
с <sub>8</sub> н <sub>18</sub>		0.1	
с <sub>9</sub> н <sub>18</sub>		0.1	
V <sub>pyr</sub> **	97.3	87.3	11.0
Total	100.0	100.0	100.0
Volatilization, % of Sample	99.2	99.8	98.3

\* Amounts of components are given in weight percent of total volatilized part. \*\*Pyrolysis products not volatile at room temperature.

RATES OF THERMAL DEGRADATION OF THERMOSET PLASTICS (Ref. 12)

Loss of Weight	Rate	%/min	0.311 at 0% loss*	0.575 "/	1.160 "	0.210 at 18% loss	0.310	0.520 "	0.167 at 20% loss	0.249 "	0.455 "	0.650 "	0.125 at 22% loss	0.204	0.385 "	0.085 at 24% loss	0.167 at "	0.318 "	0.057 at 26% loss	0.102 "	0.244 "	0.092 at 7% loss	0.154 "	0.033
	Amount	BC	39	47	51	28.4	41.7	50.7	28.4	41.7	50.7	51.0	28.4	41.7	50.7	28.4	41.7	7.04	28.4	41.7	50.7	9.6	10.1	10.4
Heatine	Duration	min	250	260	220	150	340	350	150	340	350	230	150	340	045	150	340	065	150	340	350	OTT	100	1200
Pyrolysis	Temp.	၁ <sub>၀</sub>	340	350	360	350	360	370	000000000000000000000000000000000000000	360	370	380	000000000000000000000000000000000000000	200	3/0	350	000	0/0	350	360	370	355	380	C.155
Polymer			Epoxy			Vibrin																Phenolic		

\*Values at 0% loss were obtained by extrapolation of curve.
RATES OF THERMAL DEGRADATION OF POLY(VINYLIDENE FLUORIDE), POLYACRYLONITRILE, AND POLYTRIVINYLBENZENE IN A VACUUM (Ref. 12)

Polymer Ten Ten Oc		Heat	 , ມີ	ואדאש דט אטדאי	16
00	emp.	Dura	tion	Amount	Rate*
,	Do	hr	min	Þ¢	min%∕%
Poly(vinylidene 371 fluoride) 400	71.3	ຉຓ໙຺	0000	44 101 79 100 0 0 100	0.14
1420	20		94 W	000 05 00 00	2.15
Polyacrylonitrile 218 228 240 250	88000	2914 75	4 40 0 40 0 0	0.211	0.00 0.36 0.36 0.36
260	00		0	16.5	1.14
Polytrivinylbenzene 394 420	94	44 03	0 00	10.5 10.5 14.0 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 15.5 14.0 14.0 14.0 14.0 14.0 14.0 14.0 14.0	0.03
430	0, 0 0, 0	2	50 0 50 0	40.0 47.8	0.59 1.22

\* Rates for poly(vinylidene fluoride) and polyacrylonitrile were obtained from maxima of the rate curves; rates for trivinylbenzene are based on initial rates obtained by extrapolating the rate curves to zero loss.

# MATERIALS STUDIED (Ref. 13)

	% of Resin by_wt.	Symbol
CTL-91LD on glass (Commercial high temperature phenolic resin)	(22)	(CTL)
Taylor Phenolic (Electrical grade on glass)	(44)	(Taylor)
Melamine on glass (Textolite 11508)	<b>(</b> 46)	(Melamine)
Epoxy on glass (Shell 828)	<b>(</b> 45 <b>)</b>	(Epoxy)
Novolac epoxy on Refrasil (Dew 2638.1)	(46.6)	Novolac R
Novolac epoxy on Asbestos (Dew 2638.1)	(42)	Novolac A
Polyester (Vibrin 1068)	100	Polyester
Nylon	100	Nylon
Treated nylon (impregnated with phosphotungstic acid)	100	Nylon T
Cotton	100	Cotton
Treated cotton (impregnated with phosphotungstic acid)	82	Cotton T

# CHAR AND GAS PRODUCED IN TUBE FURNACE EXPERIMENTS (Ref. 13)

Resin	Temp (°C)	Char (%)	Relative Vol Gas cc/gm	Average <u>N. W.</u>	% Tar
CTL	460 500 560 610 650 700 720 800 900 1000 1000	84.37 73.32 68.19 65.27 61.46 60.19 61.88 60.51 55.78 55.41 54.90	15.63 13.40 31.81 34.73 38.54 39.81 38.12 27.9 28.16 31.69 37.58	22.3 18.2 16.1 10.5 11.3 10.3 11.4 7.8 19.2 15.6 10.8	11.27  11.59 16.06 12.9 7.52
Taylor	500	58.53	22.73	20.8	18.74
	720	46.03	37.07	20.2	16.90
	1000	42.90	37.24	10.4	19.86
Melamine	500	41.68	6.61	20.88	51.71
Epoxy	600	13.86	15.10	27.4	71.04
	800	9.35	21.12	41.0	69.53
	1000	6.62	31.91	32.2	61.47
Novolac R	600	16.98	33.85	35.98	49.17
	800	10.88	8.71	24.1	80.41
Novolac A	600	16.97	23.37	32.2	59.66
	800	11.38	43.15	22.7	45.47
Polyester	600	5.48	17.87	40.2	76.65
Nylon	600 800	10.22 33.76		28.4 22.5	91.76 X
Nylon T	600	32.87	1.3	16.4	65.82
	800	33.16	39.37	18.5	27.47
Cotton	600	4.75	29.62	19.2	65.63
	800	49.07	42.57	31.9	8.36
Cotton T	800	43.18	43.19	26.9	13.63

# MAJOR GASEOUS PYROLYSIS PRODUCTS (Ref. 13)

Resin	Temp.	% H <sub>2</sub>	% CO	% CO2	% CH
CTL	460 500 560 610 650 700 720 800 900 1000	23.15 25.22 37.43 56.38 59.39 57.69 46.53 72.99 33.16 40.74 54.80	63.94 20.17 25.15 13.09 15.76 20.39 18.83 11.26 55.28 40.74 17.	4.41 6.73 5.93 6.26 6.66 X 2.77 2.18 4.15 2.22 1.47	6.61 17.64 21.06 21.6 17.58 16.43 16.62 11.43 5.40 7.41 12.64
Taylor	500 720 1000	21.76 49.54 65.84	10.12 17.54 23.23	15.38 2.99 3.09	25.02 21.67
Melamine	500	(22% eth	ane, 70.48%	NH3, 6.5	% сн <sub>3</sub> сн, сн <sub>3</sub> он)
Ероху	600 800 1000	13.33 27.14 28.27	22.93 15.08 18.49	28.67 21.72 23.92	14.33 15.08 8.92
Novolac R	600 800	7.68 35.41	24.49 11.36	31.06 19.26	(1.7% acrolein) (6.6% acrolein, 4% acetone)
Novolac A	600 600	24.24 11.06	36.09	32.40	(5% acrolein, 1.44% acetone)
	800	34.88	<b></b>		(8.0% acrolein, 9.8% acetone)
Polyester	600	3.29	9.10	58.42	
Nylon	600 800	18.18 14.16	(anal 25.66	yses poo 10.62	r) 14.16 (12.39% Ethylene)
Nylon T	600 800	9.52 37.71	(anal 22.38	yses poo 6.86	r) 8.66
Cotton	600	9.5	35.63	26.13	9.26
Cotton T	600 800	2.39 14.86	58.80 60.45	33.43 22.16	

The Life Sciences Group of the North American Aviation Corp. has compiled a list of materials, <u>Appendix A</u>, which are being considered for the command module of the <u>Apollo spacecraft</u>. This list is approximately 50 percent complete. Outgassing studies have been initiated by North American which are limited to a literature search <u>effort</u>. Beginning in January or February 1963 actual testing of the materials will be undertaken, utilizing gas chromatographic techniques.

The Boeing Company has compiled a list of materials, Appendix C, which had been arbitrarily selected and were not specifically identified for use in the X-20 program. This list is estimated to be approximately 30% complete. In the development state of the X-20 program, toxicity investigation is being limited primarily to an analysis and literature search. During preliminary flight rating tests of flight prototype hardware, subsystems and components will be checked for evolution of noxious or toxic products. The Boeing Company has, however, done some laboratory investigations of the thermal decomposition products of selected materials by means of the thermogravimetric analysis (TGA) method. The data from these studies are presented in Appendix D.

The Materials and Processes Group of the McDonnell Aircraft Corp. has been engaged in materials toxicity investigations since 1959. Their technique has been to determine the temperature limits of selected materials in a 100% oxygen and 5 psia environment for 24 hours continuous usage without producing any of the following:

- Irritating or obnoxious odors "sniff" tests were conducted on the effluent of the materials.
- Toxic gases no animal tests were conducted. In general, the gases were classified as toxic if the odor was irritating. (Note: This is not considered an acceptable test for toxicity.)
- Chemical deterioration (oxidation).
- \* Spontaneous flash fire or explosion due to gaseous products or the solid materials as such.

Additional tests were conducted by McDonnell to determine the physico-chemical effects of  $H_2O_2$  spillage on selected non-metallic materials. This test reflects the concern about the reactions of  $H_2O_2$ , used in the Mercury attitude control system, with other spacecraft materials. The data obtained as a result of these evaluations are included together with the lists of materials in Appendix B. This list is estimated to be 65% complete.

As previously noted, the quantities of the various materials noted in Appendices A through C for each corresponding spacecraft are not currently available. Without reference to specific hardware, it is impossible to determine a precise and completely meaningful weight breakdown analysis by material type. As an approximation, qualitative data for types of equipment can be generated for estimating purposes. For example, electronic type instruments may be considered to be composed of materials as shown in Table 18. Thus, for a four man orbiting space station containing about

			(	( n )	1
COMPOSITION	OF	ELECTRONIC	EQUIPMENT	, τ,	

Materials	Weight in G <b>rams</b> per Kilogram
Metals	
Alloy resistance wire (Evenohm) Aluminum (unfinished) Aluminum (anodized) Brass Chromium Cobalt Copper Copper (tinned) Ferrous metal Ferrous metal (hi mu) Germanium(2) Gold Lead Manganese Molybdenum Nickel Selenium Silicon(2) Tantalum(2) Tin	1 25 210 133 Trace Trace 50 35 10 5 16 Trace 5 Trace 5 Trace 13 Trace 13 Trace 13 Trace
Non-Metals	231
Carbon(2) Ceramic Epoxy (Hysol)(3) Epoxy (MPC 52 w/ceramic speres) Formex (insulating enamel) Glass Glass (fiber) Kel-F (plastic) Mylar (metallized)(2) Plastic (misc.) Teflon Miscellaneous	3.8 20 110 200 0.2 11 7 4 36 38 23 10 463 Total 1,000

- Materials breakdown averaged across three typical electronic chassis designed for flight in Project "Advent".
   Encapsulated, as in transistors, capacitors, etc.
   Large surface area.

# SUBMARINE ATMOSPHERE CONTAMINANTS

# Compounds Identified or Suspected in Submarine Atmospheres

Compound	Chemical Formula	Suspected Source	Remarks
Acetylene	C <sub>2</sub> H <sub>2</sub>		
Acrolein	сн <sub>2</sub> сн сно	Cooking	
Arsine	AsH <sub>3</sub>	Battery Gassing	
Ammonia	NH <sub>3</sub>	Scrubbers	
Carbon Dioxide	co <sub>2</sub>	Breathing	
Carbon Monoxide	со	Smoking	
Chlorine	Cl <sub>2</sub>	Chlorate Candles	
Ethylene	с <sub>2</sub> н <sub>4</sub>	Polyethylene Decomposition	
Formaldehyde	СН <sub>2</sub> 0	Cooking, Combustion	
Freon-12	CC1 <sub>2</sub> F <sub>2</sub>	Air Conditioning	See also HCl, HF, and COCl <sub>2</sub>
Hydrocarbons (other than CH <sub>4</sub> )		Paints	
Hydrogen	H <sub>2</sub>	Battery Gassing	
Hydrogen Chloride	HC1	Freon Decomposition	
Hydrogen Fluoride	HF	Freon Decomposition	
Methane	Сн <sub>4</sub>	Sanitary Tanks	
Methyl Alcohol	сн <sub>3</sub> он		
Monoethanolamine	HOCH2CH2NH2CO2	Scrubbers	
Nitrogen	N <sub>2</sub>		
Nitrogen Dioxide	NO2	Burners, smoking	
Nitric Oxide	NO	Burners, smoking	
Oxygen	0 <sub>2</sub>		
Ozone	0 <sub>3</sub>	Precipitators	
Phosgene	coc1 <sub>2</sub>	Freon Decomposition	

i.

### SUBMARINE ATMOSPHERE CONTAMINANTS (Cont'd.)

Compounds Id	lentified or	Suspected i	n Submarine	Atmospheres	(Cont'd.)
Compound	Chemic	al	Suspected		D
		a	Source		Remarks

	Formula	Source	Remarks
Stibine	sbн <sub>3</sub>	Battery Gassing	Highly unstable
Sulfur Dioxide	so <sub>2</sub>	Oxidation Sanitary Tank Gases	
Triaryl Phosphate (NOTE 4)		Compressors	

# Compounds Qualitatively Identified in Trace Amounts

Material	Chemical Formula	Material	Chemical Formula
Arsine Benzene	AsH <sub>3</sub> , C <sub>6</sub> H <sub>6</sub>	Propane Pseudocumene	с <sub>3</sub> н <sub>3</sub> 1,2,4-(сн <sub>3</sub> )с <sub>6</sub> н <sub>3</sub>
1-3-Dimethy1-5- ethy1-benzene Ethy1ene p-Ethy1 Toluene Freon-114 "Gasoline Vapors" Hydrogen Chloride Mesity1ene	1,3-(CH <sub>3</sub> ) <sub>2</sub> -5-C <sub>2</sub> H <sub>5</sub> C <sub>6</sub> H <sub>3</sub> C <sub>2</sub> H <sub>4</sub> 1,4-CH <sub>3</sub> C <sub>2</sub> H <sub>5</sub> C6H <sub>4</sub> CF <sub>2</sub> C1CF <sub>2</sub> C1 - HC1 1,3,5-(CH <sub>3</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>3</sub>	Sulfur Dioxide Toluene O-xylene m-xylene p-xylene	SO <sub>2</sub> C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub> 1,2-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub> 1,3-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub> 1,4-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub>

### Compounds Suspected as Present But Not Identified

Material	Chemical Formula	Suspected Source
Formaldehyde	НСНО	Oxidation of Methyl Alcohol
Mercury	Нд	Meters and gauges
Ozone	0 <sub>3</sub>	Electronic/electrical Equipment
Acrolein	CH <sub>2</sub> CHCHO	Cooking fats and greases
Phosgene	COC1 <sub>2</sub>	Degradation of Freon
Hydrogen Sulfide	H2S	Waste tanks
Radon, etc.	Rn	Luminous dials
Cellulube 550	(triaryl Phosphate)	Hydraulic fluids
Sodium Bisulfate	NaHSO <sub>4</sub>	CO <sub>2</sub> scrubber

300 lbs. of internally located electronic equipment, some 127 lbs. of material (from which toxic contaminants may be generated) may be included. Note that the majority of these objectionable materials are plastics and mainly epoxy base resins. Actually the quantity required to contaminate the spacecraft atmosphere may be small (assuming no atmosphere leakage). Thus, assuming a 1000 ft<sup>3</sup> free volume enclosure and using the data of Table 10, the degradation of greater than 0.06 lbs. of epoxy would result in a carbon monoxide concentration exceeding ACGIH limits. The above table illustrates the degree to which equipment materials must be considered if toxic hazards are to be eliminated.

### Submarine Atmosphere Contaminants

Naval submarine activities have long been confronted with problems of contamination of submarine atmospheres. The more recent development of the nuclear submarine has, because of its long range capability, introduced habitability problems that had not been encountered previously. An intensive atmosphere test program was therefore set up in 1956. References 14 through 16 indicate the results of this program.

Table 19 (Ref. 14) gives evidence of the broad spectrum of contaminants that have been found or suspected to occur in nuclear and fleet submarines. Although problems of the submarine and manned spacecraft are divergent in many respects, they parallel each other in a number of ways. It is therefore expected that many of the contaminants contained in submarine atmospheres, particularly nuclear powered, will also be present in manned spacecraft.

An interesting point noted in Reference 16 emphasizes the need for toxic contaminant monitoring in spacecraft. This is in reference to the fact that the toxic contaminant control equipment on-board the spacecraft may, in its operation, cause the generation of toxic contaminants. Catalytic burners using Hopcalite are commonly used in submarines (and spacecraft) for control of CO and  $H_2$  and for removal of many organic contaminants. However, if freons are present, hydrogen fluoride is formed as a product of the catalytic combustion to the detriment of crew and equipment.

### DETECTION AND IDENTIFICATION METHODS

In the selection and design of equipment to detect and identify potentially hazardous materials which may be present in spacecraft atmospheres, several concepts must be examined. The final selection will depend upon such factors as the extent of equipment required for removal of the contaminants, the type and extent of identification required, the power, weight, and volume which can be allocated for such instruments, the degree of reliability required, and the extent of participation of the occupant in preparation of such equipment and evaluation of results. As described in Section 2.0, the hazardous materials will be present in two general forms, gases and vapors, or particulate matter.

### GAS AND VAPOR CONTAMINANTS

The toxic vapor detection and identification methods employed for a specific space mission will depend to a great extent on the duration of the mission and secondarily on whether the mission is earth orbital or interplanetary. Toxic gas monitoring instrumentation could vary from no instrumentation or at most one or two specific gas sensors during a short mission such as a ballistic shot or earth orbital flight, to highly sophisticated laboratory-type analytical equipment carried in massive manned space stations over mission periods of many months. The decision to carry certain sophisticated multiple-gas type instrumentation might depend on the particular stress the spacecraft is expected to encounter; for example, high intensity ionizing radiation. In this connection the height of the orbital path above the earth during a sustained earth orbital mission could in a large measure determine the extent of the instrumentation.

For these reasons, in the discussion to follow covering multiple-gas detectors and specific gas detectors and even more extensively in the section covering instrumentation specifications as the basis for a compact toxic gas monitoring kit, mission type and duration will be a strong factor. Note also that vapor is synonomous with gas insofar as detection and identification are concerned.

### Multiple Gas Instruments

The term multiple gas detector is here used to define a single instrument whose theory of operation makes it capable of detecting, identifying and making quantitative determinations of two or more gases. Generally, a multiple gas detector can make determinations of more than two gases, usually upwards of five gases. Several of the multiple gas sensors, among them the mass spectrometer and infrared spectrophotometer, can make determinations of literally hundreds of all gases (not in a single mixture) depending upon the particular gas mixtures analyzed.

Many instrumentation techniques for multiple-gas or material analysis were subjected to a preliminary literature investigation and, as a result of the investigation, ruled out for application to space flight. Among these were: Cryoscopy, Emission Spectrometry, X-ray Fluorescence, X-ray diffraction, Nuclear Magnetic Resonance, Activation Analysis, and Microwave Spectroscopy. Most were discarded because their operation could not be reasonably compatible with the spacecraft environment due to sample preparation and analysis-energy-source requirements. Others were not included due to predicted high weight and volume requirements for a space flight package, or highly complex analysis procedures. An amperometric method for the determination of concentrations of several gases in the parts per million range, has been developed (Ref. 17). In this method advantage is taken of the fact that the diffusion current between two electrodes to which an EMF is applied is a function of the concentration of the given trace gas in a mixture with other inert gases. The method, while very sensitive and reproducible, is not as yet specific enough to distinguish a particular gas in the presence of other reactive gases.

<u>Mass Spectrometer</u>. The mass spectrometer is an anlytical instrument which identifies gases by determining their mass-to-charge ratio (essentially their molecular weight). Its output is a voltage peak, the amplitude of which is a function of the concentration of the gas, and whose position in time varies directly with the mass-tocharge ratio. Mass spectrometers utilize several techniques for separating these gases in time in accordance with their mass-to-charge ratios. Most widely used are the magnetic deflection types, time-of-flight types, and high frequency types. While the high frequency type instrument is not in wide use in the laboratory, it could well be the mass spectrometer of choice in a gas analytical system for space flight, since it appears that it can be packaged most efficiently from a volume and weight standpoint, and even more important it does not require a magnetic field (discussed later) of any type for its operation.

Any mass spectrometer, when used alone as an instrument for analyzing gaseous mixtures at near normal room temperatures and pressures, does not possess a sensitivity higher than about one part per million under ideal laboratory conditions. Rapid scan mass spectrometers, such as the time of flight type, cannot be depended upon consistently to deliver better than about 10 parts per million. When packaged for space flight this sensitivity figure will probably be even further degraded. Also these sensitivity figures are only valid when the adjacent mass peak is either several mass units removed from the peak of interest, or of equal or less concentration so peak "overlap" interference is minimized.

Physiologically, allowable concentrations of toxic contaminants are generally much less than 10 parts per million and many are less than one part per million; some even fall below 100 parts per billion (Ref. 18). Thus, the unaided mass spectrometer will fail to "see" a great many of the peaks of interest due to low sensitivity and interference from the high concentration fixed gases such as oxygen and nitrogen.

The electromagnetic deflection, and time of flight instruments are not ideally suited for long range space missions since they require electromagnets or permanent magnets of high gauss for proper operation of the instruments. An actual magnetic field measurement using a magnetometer was made at a distance of 12 inches from a time of flight mass spectrometer (Bendix Model 12). A magnetic field strength of 10 gauss maximum was recorded. Depending on the spacecraft mission, the electromagnetic fields generated by on-board equipment range from insignificant to intolerable. Even shielding does not sufficiently attenuate such hi-gauss fields. There are several effects:

a. <u>Vehicle Torque</u> - Interaction of a strong magnet with Earth's field produces torques on the vehicle, which, depending on the distance from earth, may

be the largest disturbance to vehicle attitude. For altitudes up to 20,000 nautical miles or more small size magnets produce greater torques than solar pressure or other pressures and are sufficient to be used in control systems to remove accumulated momentum from central flywheels.

- b. <u>Distortion of Field</u> Many vehicles carry magnetometers to read interplanetary magnetic fields, either to obtain data or to resolve currents among torquing coils. These will be nullified by the presence of a large artificial field in the vehicle.
- c. <u>Instrumentation</u> In some cases operation of guidance or control instrumentation may be susceptible to magnetic fields that can exist near devices with large magnets.

These and other factors are sufficiently important that component specifications for some vehicles have quoted stringent requirements with respect to inherent magnetic fields.

Two important advantages of the mass spectrometer are: the extremely small sample size required (Approx. 0.2 cc/min at 0.2 mm of pressure) and the inherent ability to "see" an unknown gas by its molecular weight. Thus, an unpredicted gas, provided its concentration was above the instrument threshold and provided high concentration masking gases were absent, could not go unnoticed.

<u>Gas Chromatograph</u>. A gas chromatograph consists basically of 3 parts: the sampling system, a column and a detector. Helium is generally used as a carrier gas; however, argon, nitrogen and hydrogen have also been used and, no doubt, several other gases have been used experimentally. Commonly, the detector is a device which generates either a zero electrical signal, or a DC electrical signal when only the carrier gas is passing through it, but delivers a varying signal, or AC signal when any other gas appears mixed with the carrier gas. The AC signal is also normally proportional in amplitude to the concentration of the contaminating gas in the carrier.

In operation, carrier gas is allowed to flow through the entire system at a rate between 10 and 400 cc per minute, the exact rate of flow depending upon the particular equipment at hand and the type of analysis being performed. The carrier gas allows the various gases in the sample mixture to lag the carrier due to the selective retardation exerted by the stationary phase. The carrier gas sweeps the sample gas mixture through the column containing the solid adsorbing or liquid partitioning agents. Thus the components of the mixture move through the column, effectively at different flow rates.

It should be noted that the partitioning columns are designed for specific mixtures of gases. An unknown (and thus unexpected) trace gas could therefore not be detected. This is an important and often unrealized disadvantage of the gas chromatograph for toxic contaminant detection and identification. The detector in a gas chromatograph is probably the most critical component of the entire instrument. It is the detector which determines the ultimate sensitivity of the instrument and determines also to a large extent the types of gases which can be detected. Several of the most widely used detectors, as well as a new detector which shows great promise, are briefly described. a. <u>Thermal Conductivity Detector</u>. This detector depends for its operation upon the differential thermal conductivity of different gases. Hot wire elements or thermistors are generally used. This type of detector has two outstanding advantages. It requires very simple output circuitry, and it will detect any gas of sufficient concentration whose thermal conductivity is different from that of the carrier gas. On the deficit side of the ledger, however, is its poor sensitivity; it cannot be depended upon to deliver a sensitivity of better than 100 parts per million and most generally the sensitivity is on the order of 500 parts per million to many of the gases of interest. In the realm of toxic gas detection this detector is useless, since most MAC's require much higher sensitivity levels for measurement (Ref. 18).

b. <u>Hydrogen-Flame Ionization Detector</u>. The hydrogen-flame ionization detector, as in the case with most ionization detectors, is between  $10^3$  and  $10^4$  times more sensitive than the thermal conductivity detector. The one advantage of this detector is its high sensitivity to certain gases. The detector is insensitive to inorganic compounds, except for some containing elements in groups I and II of the periodic table. It will respond to all organic substances except formic acid,  $CO_2$  and CO. Its sensitivity to organic compounds is approximately proportional to the carbon number, except for those compounds which are oxygenated or contain nitrogen. Calibration is very critical in this detector for quantitative results, and is much dependent upon detector design and gas flow rate. The sophistication of this detector, its critical nature and the fact that a hydrogen flame is required, would appear to make it unsuitable for spacecraft use.

c. <u>Argon Ionization Detector</u>. Several versions of this detector have been developed, with much of the work being done by J. E. Lovelock (Ref. 19). These versions have varied from models with sensitivities not much better than a thermal conductivity detector, to sensitivities even higher than some hydrogen-flame ionization detectors. Again, the sole advantage of the argon ionization detector lies in its high sensitivity. It has an additional advantage over the hydrogen-flame detector in that a flame is not required. However, the same sophisticated readout circuitry is required.

The argon ionization detector will detect most organics and in addition, some of the simple gases not detectable with the hydrogen flame, such as  $H_2O$ , NO, NO<sub>2</sub>, NH<sub>3</sub>, PH<sub>3</sub>, BF<sub>3</sub>, and others. As with the hydrogen-flame ionization detector, the argon detector will not respond to H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, CO (CN)<sub>2</sub>, H<sub>2</sub>O, and also fluorocarbons. In general, all organics which have ionization potentials of less than 11.7 electron volts can be detected. However, the several critical toxic gases noted above cannot be seen by this detector and therefore, it would appear to be unwise to carry this instrument as the only multiple gas detector on a particular space mission without the inclusion of several backup specific gas detectors.

d. <u>Karmen Glow Discharge Detector</u>. The Karmen Glow Discharge detector is a very recent development in the field of gas chromatography detectors. Dr. Arthur Karmen, et al (Ref. 20 and 21) working in the Technical Development Laboratory of the National Heart Institute with a form of the Lovelock ionization detector, noted that when helium was used as the carrier gas and the intensity of the radioactive source was increased — this normally produces an increase in current in the detector — for a given voltage across the cell, current failed to increase beyond  $10^{-7}$  amps. regardless of the intensity of the radioactive source. When Karmen removed the radioactive

source and operated the detector from a constant current power supply, a stable glow discharge was initiated in the detector. A schematic representation of this detector is shown in Figure 5. The breakdown voltage across the cell was found to be a function of the impurity in the helium. Since the sequential effluent gases, contained in the original sample injected into the column of a gas chromatograph, are essentially contaminants of the carrier gas as they leave the column, Karmen found he had an extremely sensitive detector, which could see the light permanent gases as well as organics.

Sensitivities to several of the light permanent gases measured were as good or better than sensitivities to organics obtained in other ionization detectors. An additional advantage possessed by this detector is that the output signal is biphase, depending upon the concentration of the particular contaminant. Figure 6 is an approximate plot of this characteristic. As the concentration of the "contaminant" gas in the helium increases from 0 to approximately 100 parts per million, the effective glow discharge resistance reduces and therefore the voltage across the cell goes negative. However, as the concentration continues to increase, a point is reached where the slope abruptly reverses due to partial quenching of the glow discharge due to the high concentration contaminant. The negative going characteristic for the extremely low concentration has the steepest slope, a desirable characteristic for a toxic gas detector.

While this detector has recently been introduced to the art, it is not at present being marketed and perhaps has certain disadvantages which are yet to be discovered. It appears to be a detector which will supply the gas chromatograph with a high sensitivity, as well as an "across the board" detector of essentially all gases that are separated in the column. With the advent of this detector, even with its sophisticated readout circuitry, the use of the gas chromatograph as a multiple toxic gas detector during space missions becomes much brighter.

### Spectrophotometers

In the present state of the art of spectrophotometry for gas analysis, two instrument types are much used in the laboratory. One type is the infrared spectrophotometer and the other instrument is the UV and visible spectrophotometer. Between the two instruments including accessories, practically all gases and vapors can be detected provided they are of sufficient concentration. For organic gaseous forms, without resorting to extremely cumb ersome me thods of handling the sample, only the infrared instrument is of value; sensitivities between 20 and 100 parts per million are feasible.

Spectrophotometric instruments for gas analysis, while valuable as complementary instruments in the laboratory, are considered to pose severe problems where redevelopment and redesign for space vehicle applications are undertaken. In order to achieve even reasonable sensitivity (better than 100 parts per million), complex, long optical path-lengths are required and/or samples at high pressures are necessary. These long path lengths make instrument volume reduction difficult. In addition, the optics required for infrared transmission and refraction are generally adversely affected by high humidity conditions. This could interfere seriously with the reliability of the instrument.





<u>Condensation Nuclei Gas Analyzer</u>. A relatively unknown toxic gas analyzer technique is the concept of Condensation Nuclei detection. For certain toxic contaminants this detector is now operational, being marketed by General Electric for the detection of hydrazine and other toxic substances (Ref. 22). Figure 7 shows the basic Condensation Nuclei Gas Analyzer. Some typical concentration sensitivities for the condensation nuclei type gas analyzer are shown in Table 20, (Ref. 23).

### TABLE 20

### CONDENSATION NUCLEI GAS ANALYZER DETECTION SENSITIVITY

Substance	Minimum Concentration, ppm	<sub>TLV</sub> (1)
Carbon Monoxide	1.0	100.
Methyl Mercaptan	0.01	50.
Mercury (vapor)	0.001	0.1
Nitrogen Dioxide	0.5	5.
Sulfur Dioxide	0.001	5.

### (1) ACGIH Threshold Limit Values for 1962

The gas mixture to be analyzed is passed first through a particle filter to remove any ambient nuclei present in the sample (in practice down to less than 50 particles per cc.). It then is passed through a reaction section where the specific gas or group of gases of interest are converted to an aerosol by one of a number of photochemical, chemical or thermal processes. This aerosol, consisting of fine particles which can act as condensation nuclei, together with the remaining gas constituents, are then passed through a humidifier to achieve a 100% relative humidity condition. The humidified mixture then flows through the first section of a rotary motor driven valve into the expansion chamber. After a brief dwell period, the second section of the rotary value opens, exposing the expansion chamber to a source of regulated vacuum. The sudden expansion results in adiabatic cooling of the gas sample causing the relative humidity to rise above 100%. The water vapor will then condense out on any nuclei present. The resulting droplets soon grow in size to where they can scatter light. The expansion chamber contains a dark-field optical system which delivers no light to the photomultiplier tube in the absence of fog droplets. With droplets present in the chamber, light is caused to be scattered to the photomultiplier. The amount of light received is proportional to the number of droplets (each one containing a nucleus), and to their scattering area.

One disadvantage of a condensation nuclei type instrument used for gas analysis is the inherent selectivity. A condensation nuclei instrument can only detect and identify the specific gas (or group of gases) for which it is designed. Thus, as with the gas chromatograph, detection and/or identification of unanticipated gas constituents cannot be accomplished. If specific identification is not required, conversion of all contaminants in the atmosphere sample to condensation nuclei is a possible alternative. This concept has been explored to some degree (Ref. 23) with promising results obtained. This can result in a highly sensitive instrument which will be sensitive to total contaminant concentration. With consequent simplification of the instrumentation, it becomes a consideration for application to spacecraft.



Figure 7. Condensation Nuclei Gas Analyzer Schematic

Multiple Gas Instrument Combinations. When two or more analytical instruments are combined during the analysis of a given gas mixture, it is obvious that greater accuracies from both a qualitative and quantitative standpoint can be achieved, especially when positive detection and identification of a given toxic contaminant is desired. Probably the most powerful combination in the state of the art today is the gas chromatograph and mass spectrometer (Ref. 24). While these instruments by themselves are powerful multiple-gas analytical instruments, they both possess certain disadvantages. For example, the gas chromatograph requires a column which has been specifically designed to separate the gases of a specific gas mixture. It is often extremely difficult to design a column complex to separate in time, one or more of the specific gases from a complex multi-gas mixture. Present state of the art detectors used as part of gas chromatographs have combinations of desirable and undesirable characteristics as previously discussed. A major disadvantage when using the gas chromatograph alone, regardless of the form of detector, is the possibility that it will fail to identify a gas for which the chromatograph column has not been designed, since the instrument does not identify gases by a fundamental property as does the mass spectrometer. The major advantages of the gas chromatograph lie in its ability to physically separate a gas mixture, and, when using ionization detectors specific to certain groups of gases, to detect down to parts per billion.

The mass spectrometer, on the other hand, when analyzing a gas mixture, displays spectra for all gases in the mixture simultaneously. This can cause overlapping of the gas spectra and therefore make it difficult to determine whether a given spectral peak is a cracked product of one gas or another. Its major advantage lies in its ability to identify a given gas by a fundamental characteristic of the gas; the molecular weight to charge ratio.

Combining these two instruments can thus be seen to form a powerful tool for gas analysis. In such an arrangement, the mass spectrometer becomes an extremely versatile, high-resolution, identifying detector for the gas chromatograph. However, the present dependable sensitivity is no better than about 100 parts per million for a unit packaged for spacecraft use.

Concentration and Separation. Concentration and separation in one form or another has been a widely used technique for supplementing detection and identification instrumentation for detecting trace gases at very low concentration levels. In mass spectroscopy, for example, the spectra of high concentration gases (such as oxygen and nitrogen) and low concentration gases (such as some of the toxic contaminants) can overlap. Thus critical toxic contaminants of low concentration can be masked. Also the sensitivity of a mass spectrometer designed for space use cannot reliably be expected to exceed about 100 parts per million. Separation and concentration techniques can improve the effective sensitivity of the mass spectrometer down to well below the one part per million range. Freeze-out is commonly used in mass spectroscopy for separating condensables from non-condensables in order to minimize masking. Southwest Research Institute (Ref. 25) employed various physical and chemical techniques to separate and concentrate metabolic trace constituents from some 60 liters of expired air. Gas concentrations as low as 0.0001 ppm (referenced to the original volume) were detected. Flight type hardware for trace gas concentration and separation does not presently exist; no great difficulty is anticipated in adapting laboratory concentration methods for spacecraft applications.

Separation and concentration techniques are not limited to use in mass spectroscopy. These techniques are equally useful in conjunction with spectrophotometers and condensation nuclei type instruments. A gas chromatograph inherently provides separation; however, concentration is still a useful tool to provide for detection and identification of gases in the less than one part per million range.

<u>Instrument Comparison Table.</u> Table 21 summarizes the capabilities of the various gas analytical instrumentation discussed in this study. Reference to this table can allow rapid comparison and selection of the multiple gas instrumentation required for a specific mission.

### Specific Gas Instruments

For missions too short to justify complex instrumentation or as an emergency back-up gas sampling system for longer missions, specific gas detection for a few of the most important toxic gases may be of value. At the present time there are available from several manufacturers, relatively compact kits containing a basic gas sampling apparatus together with glass tubes containing proper reagents supported on some inert absorbent. By passing a metered volume of gas through such tubes, the concentration of the unknown gas is determined visually by the color change of the reagent as well as by the length of the tube affected by the color change. In many instances, the color change is not very distinct especially when other reactive gases are present. In such cases accuracy of the gas concentration determination may vary considerably and may even lead to completely erroneous results. The errors of gas concentration measurements using such specific gas detector tubes can be considerably decreased by providing the operator reference color standards with which to compare color changes of the reagents. Such color standards are particularly useful in areas of varying illumination and intensity as well as spectral balance.

It has been the experience of the Naval Research Laboratory personnel engaged in chemical research in atmosphere purification and control on nuclear-powered submarines, that thorough training of operators using the gas analysis tubes greatly increased the accuracy of gas concentration determinations (Anderson, W., NRL Personal Communication, November 1962). However, even under most favorable conditions, the accuracy that can be attained with this technique seldom exceeds 20 percent. In many cases the ratio of apparent concentration to true concentration may be in the range from 0.25 to 4.0 (Ref. 26).

In spite of these inadequacies, colorimetric tubes may be found to be useful in spacecraft applications to give at least approximate concentration of toxic gases in the atmosphere.

While many specific colorimetric tubes for a long list of gases have been developed, it is very unlikely that more than about five or six kinds would be needed in a spacecraft, simply because from the detailed knowledge of materials to be used in such a vehicle it will be known a priori that certain gases cannot be present under any circumstances. In addition, a close identification of all the gases is not required. It will be sufficient to identify certain families of toxic gases if present in concentrations near or above the allowable limit. The suggested tubes are:

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# COMPARISON OF MULTIPLE-GAS DETECTOR PERFORMANCE CHARACTERISTICS

Packaged For Space	F 11ghc?	yes (Develop- ment model	only) yes (Develop- ment model only)	ou		ou	92	ю	yes (Develop- ment model culv)	UU UU	ou
State	OI AFC	present	present	present		present	present	present	"just about"	present	future (for space)
Quanti- tative abilite	ATTIAN	very good	very good	poog		excellent	Poos	poos	good	good	very good
Sampling Stand	obeen	2 to 5 minutes	Up to 10, 000 com- plete spec- tra per sec.	Up to 10 complete spectra per		2 to 15 mfnutes (1)				0 to 10 mínutes	5 per second for total con- taminant
Samp le Stze		small as 100 cc				1 to 5 cc (1)			-	100 to 1000 cc	20 cc
Resolution		excellent	excellent	very good		very good for specific column (1)			-	very good	N.A.
Specificity		excellent	excellent	excellent		very good for specific column (1)				very good	N.A.
Sensitivity (Dependable)		10 to 100 ppm	10 to 100 ppm	10 to 100 ppm		100 to 1000 ррт	l to 10 ppm	l to l0 ppm	1 to 10	20 to 100 ppm	0.1 to 10 ppm
Gases Or Types Of Gases Detected		all to m/e=100	all to m/e=100	all to m/e≡100		all	all organic except formic acid, CO2, and CO. no inorganics. See 3.2.2.2	most organics plus H <sub>2</sub> 0, N0, N02, NH <sub>3</sub> , PH <sub>3</sub> , BF <sub>3</sub> , & Others See 3.2.2.3	a11	Most organics in addition to CO and CO <sub>2</sub>	Total toxic contaminant
Hi gauss Magnetic Fields Required?		Yes	yes .	ou		ou	ou		on G	01	
Sensing or Separation Method		Mass to charge		>		Adsorbence & partition delay in a columm (1)				Absorption coeffic- ients of gas	Differen- tial No light scat- tering by water drop- lets
Instrument	Mass Spectrometer	1 Magnetic Deflection	2 Time-of- Flight	7 Frequency	Gas Chromatograph	<pre>1 Thermal Conduct1- vity Detector</pre>	2 H <sub>2</sub> flame Idnization Detector	3 Argon/ Ionization Detector	4 Karmen Detector	, , , , , , , , , , , , , , , , , , ,	Condensation Nuclei Detector

(1) applies to gas chromatograph in general

- 1. Carbon Monoxide (in the presence of hydrocarbon and nitrous gases).
- 2. Benzene and other aromatics.
- 3. Hydrogen sulfide, sulfur dioxide.
- 4. Chlorine and halides.
- 5. Ammonia and amines.
- 6. Hydrogen fluoride.

In addition to the above tubes, a tube for detection of mercury may also be included, should there be a possibility of mercury spillage.

A complete list of available gas detector tubes manufactured by Kitagawa of Japan and Mine Safety Appliance Co. have been compiled in Table 22. The Kitagawa tubes are distributed in this country by Union Industrial Equipment Corporation, Port Chester, New York.

The gas-detector tubes are supplied with a hand operated pump designed to draw air samples at a reproducible, fixed rate through the detector tubes. If no color change in the tube develops after one pump stroke, the procedure is repeated until a color change appears or until such time at which there is assurance that the gas in question is not present at a concentration greater than the minimum detectable value. Thus each analysis can be quite time consuming if the particular gas is absent or present in very low concentration. In order to speed up the analysis, the atmosphere sample may be drawn through tubes arranged in parallel, or still better, drawn through the tubes in sequence. In this manner a complete analysis for about a half dozen gas families can be performed within the time period which may be required for one specific gas existing in low concentration.

### Instrumentation Specifications as Basis for Compact Kit

Probably the most important piece of information confirmed during the detection and identification methods portion of this study, is the lack in the present state-ofthe-art of a versatile instrument for monitoring toxic gases and vapors. No instrument exists, which exhibits in the same instrument, the sensitivity, specificity, and range of gases detected, required of an instrument for monitoring the spacecraft atmosphere during intermediate range and long range space missions. In the immediate future state-of-the-art, with the advent of the Karmen detector, techniques involving the gas chromatograph appear promising, as does the high frequency type

### GAS DETECTOR TUBE

GAS	MEAS. RANGE	MAC	TUBE NO.	SOURCE	INTERFERENCE
Acetone	.05-5%	0.1%	102A	Kitagawa	Organic vapors, H <sub>2</sub> S
Acetylene	3-600 ppm		82802	MSA Co.	BO2 Hydrocarbons, CO,
Acetylene	50-100 ppm		101	Kitagawa	Hydrocarbons, CO,
Arsine	.05-1 ppm	.05 ppm	87031	MSA Co.	SbH <sub>3</sub> , PH <sub>3</sub>
Acrylonitrile high-range Acrylonitrile	0.1-3.5%	.002%	128A	Kitagawa	Organic vapors
low-range	10-500 ppm	20 ppm	128B	Kitagawa	Organic vapors
Ammoniahigh- range Ammonialow-	1-25%	0.01%	105A	Kitagawa	Organic vapors
range	20-700 ppm	100 ppm	105B	Kitagawa	Amines
Arsine	5-160 ppm	.05 ppm	140	Kitagawa	H <sub>2</sub> S, PH <sub>2</sub>
Benzene	10-310 ppm	25 ppm	118A	Kitagawa	Aromatics
Benzene	10-100 ppm	25 ppm	72986	MSA Co,	Aromatics
Benzene(in pre-					
sence of					
aromatics)	25-345 ppm	25 ppm	<b>118</b> B	Kitagawa	Toluene above 500ppm
Bromine	5-75 ppm	0.1 ppm	82399	MSA Co.	$H_2S, NH_3, NO_2, C_2H_4,$
Bromine	5-200 ppm	0.1 ppm	87042	MSA Co.	$H_{2}S, NH_{3}, NO_{2}, C_{2}H_{4},$
Bromine	10-300 ppm	0.1 ppm	114	Kitagawa	Halogens, ozones,
			ų		nitrous gases
Carbon dioxide	.05-1%	0.5%	85976	MSA Co.	
Carbon dioxide					
high range	0.1-2.6%	0.5%	126A	Kitagawa	acid gases at high
~ · · · · · ·					concentrations
Carbon dioxide	000 700	5000	10.00	<b>TR A</b> .	
low-range	300-700 ppm	5000 ppm	126B	Kitagawa	acid gases at high
Combon Diamida I					concentrations
tupo	1_20%	0.5%	1261	Kitagawa	and many at high
cype	1-20%	0.5%	1201	MILAGAWA	concentrations
Carbon Monovide	001-0 1%	0.01%	47134	MSA Co.	NO2 Co Ha Hydro-
Carbon Monoxide	25-6000 ppm	100 ppm	1064	Kitagawa	carbons C. H.
sarbon nononiae	25 0000 ppm	TOO bbm	10041	ni Luguwu	CoH2, nitrous gases
					HCN Has
Carbon Disulfide	10-200 ppm	20 ppm	141	Kitagawa	Hos above 50 ppm.
	FF				SO <sub>2</sub> 150 ppm
Carbon Monoxide	25-6000 ppm	100 ppm	106B	Kitagawa	Hydrocarbons, C <sub>2</sub> H <sub>2</sub> ,
				Ŭ	H <sub>2</sub> S, HCN, Nitrous
					gases
Carbon Monoxide	25-600 ppm	100 ppm	106C	Kitagawa	C <sub>2</sub> H <sub>2</sub> , HCN
Chlorine	0.5-20 ppm	1 ppm	82399	MSA Co.	Halīdes
Chlorine	3-100 ppm	1 ppm	87042	MSA Co.	Halides

					·····································
	MEAS.		TUBE		
GAS	RANGE	MAC	NO.	SOURCE	INTERFERENCE
Chloring	1-40 000	1 nnm	1.09	Kitagawa	Helogens 0
Gillorine	T-40 bbm	r bbw	205	Mi cubana	nitrous gases
Chlorine Dioxide	10-500 ppm	0.1 ppm	116	Kitagawa	Halogens, 03,
		_			nitrous gases
Chlorobenzene	10-200 ppm	75 ppm	85834	MSA Co.	Halogeus, halides
Carbon Tetra-	5 200	25 nnm	1/7	Vitagoua	
Cyclohevane	100-6000 ppm	400 ppm	115	Kitagawa	Organic vapors
Decaborane	0.01-1 ppm	.05 ppm	82099	MSA Co.	Hydrazine, UDMH,
			•		H <sub>2</sub> S
Diborane	0.1-3 ppm	0.1 ppm	82099	MSA Co.	Hydrazine, UDMH,
					H <sub>2</sub> S
0-dichloro-	10.000	50	05004		
benzene	10-200 ppm	50 ppm	85854	MDA CO.	Halogens, halldes
lorethylene	25-400 ppm	200 חתת 200	85833	MSA Co.	Halogens, halides
diethvl ether	400-1400 ppm	400 ppm	107	Kitagawa	Organic vapors
Dimethyl ether	100-1,200,			U	0
-	000	50 ppm	123	Kitagawa	Organic vapors
Ethanol	0.04%-5%	0.1%	104A	Kitagawa	Organic vapors,
1941 - 1 1	25 /00	200	0502	MCA Co	$H_2S$ , $SO_2$
Ethyl bromide	23-400 ppm	200 ppm	85833	MSA Co	halogens, halides
Ethvlene	0.5-100 ppm		1.08B	Kitagawa	$CO_{2}CO_{2}H_{1}H_{2}S_{2}$ HCN
Ethylene	0.5-100 ppm		82802	MSA Co.	$CO, NH_3, H_2S,$
					hydrocarbons
Ethylene oxide	0.01-3.5%	005%	122	Kitagawa	Organic vapors,H2S
		0.5%			SO <sub>2</sub>
Hexane	0.01-0.6%	.05%	113	Kitagawa MSA Co	Organic vapors
Hydrogen Cyonide	2-50 ppm		73497	MSA Co.	NH2, H2S
Hydrogen Cyanide	0.01-3%	.001	112A	Kitagawa	Cyanogen, $H_2S$ , $SO_2$
Hydrogen Fluoride	0.5-5.0 ppm	3 ppm	8123	Kitagawa	
Hydrogen Sulfide					
high-range	0.01-0.17%	0.002%	120A	Kitagawa	so <sub>2</sub>
Hydrogen Sulfide	5 160	20	1200	Vitegan	50-
LOW-range Hydrogon Sylfide	1-800 ppm	20 ppm	87616	MSA Co	502 50a
Hydrogen Sulfide	1-000 ррш	20 ppm	07414		502
in presence of SO <sub>2</sub>	.005-0.16%	.002%	120C	Kitagawa	HC, CO, Nitrous gas,
	2				HCN
Mercury	0.05-2 mg/m <sup>3</sup>	$0.1 \text{ mg/m}^3$	83089	MSA Co.	
Mercury	[0.1-2 mg/m <sup>3</sup>	0.1 mg/m <sup>3</sup>	142	Kitagawa	CL <sub>2</sub> , NO <sub>2</sub>
Methanol	0.01-6%	0.02%	119	Kitagawa	Ho S SOO
Methyl bromide	10-500 ppm	20 ppm	157	Kitagawa	halogens, nitrous
1.2011/2 02011200					gases
Methyl bromide	10-100 ppm	20 ppm	85834	MSA Co.	halogens, halides
Methyl Ethyl		1			
Ketone	0.01-1.4%	0.02%	139B	Kitagawa	Organic vapors
Nickel carbonyl	20-700 ppm	10.001 ppm	87000	KITTAGAWA	Has balidas
Nitrogen Dioxide	1-1000 ppm		117	Kitagawa	halogens. 02. NoOs
THE COM PEORE	- 2000 PPm	- FF			

### TABLE 22 (CONTINUED) GAS DETECTOR TUBES

مى جور	Y				÷
GAS	MEAS. RANGE	MAC	TUBE NO.	SOURCE	INTERFERENCE
Pentaborane	0.01-1 ppm	.005 ppm	82099	MSA Co.	Hydrazine, UDMH, H <sub>2</sub> S
Perchloroethylene Phosphinehigh	10-300 ppm	100 ppm	85833	MSA Co.	Halogens, halides
range Phosphinelow	20-800 ppm	0.05 ppm	121A	Kitagawa	H <sub>2</sub> S, As H <sub>3</sub>
range	5-90 ppm	0.05 ppm	121B	Kitagawa	H <sub>2</sub> S, As H <sub>3</sub>
Propylene	1-400 ppm		82802	MSA CO.	NH3, H2S, CO, HC
Sulfur dioxide	1-50 ppm	5 ppm	/4354	MSA Co.	$H_{2}S, NH_{3}, Cl_{2}$
middle-range Sulfur Dioxide	0.043%	5 ppm	103B	Kitagawa	н <sub>2</sub> s
low-range Sulfur Diovide	5-300 ppm	5 ppm	103C	Kitagawa	н <sub>2</sub> S
D-type	1-80 ppm	5 000	1030	Kitagawa	Hos
Toluene	1-1000 ppm	200 ppm	124	Kitagawa	Aromatics
Toluene	5-400 ppm	200 ppm	72986	MSA Co.	Aromatics
Trichloroethvlene	25-600 ppm	100 ppm	85833	MSA Co.	Halogens, balides
Trichloroethylene					
(perchloroethylen	e)				
	10-400 ppm	100 ppm	134	Kitagawa	Halogens, halides
UDMH	0.5-10 ppm		81977	MSA Co.	-3, meebus gabes
Xylene	10-400 ppm	200 ppm	72986	MSA Co.	Aromatics

# TABLE 22 (CONTINUED)GAS DETECTOR TUBES

mass spectrometer in combination with a trace gas separation and concentration technique. A long range look at the future state-of-the-art of multiple gas detection instruments indicates promise in the General Electric Condensation Nuclei type instrumentation. The amperometric technique may also be useful to measure total contaminant concentrations.

Materials in use and being considered for use in spacecraft, under both predicted and unpredicted stresses of space flight, can be expected to off-gas numerous toxic contaminants. In the ideal case where none of the materials used in the spacecraft are those which might off-gas toxic contaminants, there would still exist, as a minimum, the off-gassed products of metabolism from the man himself. Therefore assuming a leak-tight spacecraft, numerous toxic contaminants could build up to unacceptable concentrations in a relatively short time (assuming partial or complete failure of the contaminant control equipment). Thus monitoring by gas analytical instrumentation which possess the necessary resolution and sensitivity is required. To cover any eventuality, all missions in excess of a few days duration would include on-board gas analytical instrumentation exhibiting the following performance capabilities:

### a. Resolution

Resolve toxic contaminants in the presence of the normal gases (oxygen, diluent and water vapor) which exist in the spacecraft breathing atmosphere. As noted above, a minimum spectrum of toxic contaminants is that generated by the man himself. Table 1 lists these constituents.

### b. Sensitivity

Exhibit a sensitivity high enough to discern above the instrument background noise the threshold concentration of any toxic gas or gases expected. This threshold concentration should be an order of magnitude below the unacceptable level for the particular gas involved. A threshold sensitivity of 0.01 ppm appears desirable.

### c. Fundamental Mode of Analysis

The method of analysis should allow the identification of gases which may be unpredicted.

### d. Sampling Rate

The time from one analysis to the next should be short enough (between 0.1 to 5 min.) to safely monitor the possible rapid build-up of contaminants. In the event the spacecraft environmental control system functions are being operated directly from this instrumentation, the time must be short enough (between 0.01 and 5 seconds) to maintain the stability of the control system and supply the necessary information rate.

### e. Sample Flow

The sample flow must be small enough to minimize loss of spacecraft atmosphere (where the analytical technique destroys the sample or discards it outside the vehicle).

### f. Fail Safe Characteristics

The instrumentation must indicate in some way when its data are no longer valid.

### g. Signal Output Characteristics

The output of the instrumentation must be capable of modulating telemetry signals as well as operate on-board readouts.

### h. Reliability

The mean-time-to-failure of the instrumentation including redundancy effects must be consistent with the mission length.

### i. Accuracy

Plus or minus 10% of full scale.

### j. Environmental Conditions

The instrumentation must be capable of meeting the performance requirements when subjected to the following environmental conditions or rational combination thereof:

Environment	Range
Temperature	0 to 150 <sup>0</sup> F
Pressure	ambient to vacuum
Radiation	5 REM max. normal, 100 REM max. emergency
Humidity	0 to 100% RH
Acoustics	135 db between 40 and 9600 cps
Acceleration	20 g along each of three mutually perpendicular axes
Vibration	±2.3 g's, 20 to 50 cps 0.018 in. double amplitude; 50-112 cps 11.4 g's; 112-2000 cps (along each of three mutually perpendicular axes).
Impact Shock	20 g's for 10 milliseconds along each of three mutually perpendicular axes.

The selection of actual instrumentation to identify and detect toxic contaminants will depend on mission type and duration. This is illustrated below for assumed mission type and duration.

### a. Short Missions

Short missions may be defined as earth orbiting flights or the equivalent of durations up to several days. Because of the short period, toxic gas monitoring instrumentation no more complicated than several of the specific single-gas detectors previously described will be required. The specific single-gas detector chosen for a particular short mission will depend on data developed during spacecraft design and ground testing, the results of which will permit prediction of those gases which will require monitoring. Note that in Project Mercury, the high permissible leak rate from the capsule negates any requirement for toxic gas monitoring.

### b. Intermediate Missions

Flights in the intermediate range category may be defined as earth orbital flights of duration up to several weeks and/or lunar voyages. Toxic gas monitoring instrumentation for this class of mission will be more complicated, consisting of a multiple gas analysis instrument such as a gas chromatograph plus back-up specific single gas detectors for predicted, problem gases. The relative short duration mission will permit extensive ground testing prior to flight.

### c. Long Missions

Extended range missions, defined as inter-planetary voyages and manned space station occupancy of durations up to a year and more, will require multiple gas analysis instruments capable of detecting a wide range of gases and vapors, many of which may not be predictable by ground testing or even past mission data. This requirement would most certainly point to an instrument, such as the mass spectrometer in series with a trace gas separation and concentration technique wherein detection and identification depends on a fundamental characteristic of the particular gas or vapor.

### PARTICULATE CONTAMINANTS

As for gases and vapors, the detection and identification methods employed for particulate contaminants for a specific spacecraft will depend to a large extent on the type and duration of the mission. Also, and in particular for long duration missions wherein prior ground testing may not be 100% effective, the generation of particulate contaminants, both anticipated and unanticipated, must be assumed. For spacecraft use, instrumentation must be provided to determine both concentration, in terms of total number and/or weight of particles within the critical size range, and the chemical composition. Both are required to determine whether or not particulate contaminants are within tolerable limits.

### Instrumentation

Tolerable limits for particulate contaminants are listed by the ACGIH (Ref. 18) in terms of both milligrams per cubic meter and millions of particles per cubic foot (based on impinger samples counted by light-field techniques). Thus metallic dusts and fumes are reported in terms of weight concentration; however the error in appraisal of hazard may be considerable because of coarse particles in the sample. On the other hand, mineral dust is reported in terms of number of particles. This latter practice does not compensate for differences in size within the hygienic range below 5 micron. Equal number concentrations of one and three micron size particles will not represent the same degree of hazard because of differences in alveolar deposition and in basic toxicity. Conversion from one to the other requires a knowledge of both particle size and particle density.

Detection. Many techniques have been devised for determination of atmosphere particulate concentration for both laboratory and field use. These sampling instruments may be categorized according to collection mode as follows: settlement, both gravity and centrifugal; filtration; impingement; and precipitation (Ref. 27). In general particles are collected on slides or the equivalent with concentration for a given size range of particles determined by a combination of microscopy, gravimetric. and chemical techniques. Electric and thermal precipitators and various filter media are superior to impingement type relative to collection efficiency for the complete particle size range of interest. The molecular or membrane filter and thermal precipitator have the added advantage of depositing particles without physical alteration and in such a manner as to permit direct microscopic examination without disturbing the particles. By making particle size measurements on the collected sample along with the particle count, concentrations may be reported for each size increment, thus greatly increasing understanding of the nature of the contaminant exposure. In contrast, impingement-type instruments (used exclusively in the U.S. Public Health service as a basis for determining tolerable exposure limits) have low absolute collecting efficiency for particles smaller than one micron. Also disaggregation and shattering of particles occurs to various exterts in impingement type devices, further clouding the actual particle size distribution. In addition to optical microscopy, size distribution may be determined by elutriation or electronic microscopy. Electron microscopy offers an order of magnitude improvement in minimum particle size measurement, the limit of resolution for the optical microscope being about 0.4 microns.

In general, sampling rate is dependent upon the physical limitations of the instrumentation employed rather than upon any physiological reasons. A relatively rapid sampling rate has the advantage of providing both trend information and, by integration, longer term averages. The importance of sampling rate depends on the type and weight rate of contaminant release. Silicosis requires prolonged (many year) exposure, whereas lead intoxication may develop after a few months. Poisoning from cadmium fumes or a toxic organic dust may result in a few hours.

Dusts and smoke can be visually observed when present in high concentrations. Harmful materials of low toxicity, such as zinc oxide, are readily visible under favorable conditions. However, concentrations on the order of 1 mg per cubic meter (well above the safe limits for cadmium and lead) are not easily observed.

For automatic type instrumentation, a continuous indication of particle count and size distribution may be obtained using detectors employing a light scattering technique. The Rayco photometer, using a dark field optical system, in combination with a gated counter can determine the number of particles ranging from 8 to 0.2 microns in diameter in a number of discrete size steps. Accuracy is somewhat better for relative than for absolute number; performance degrades if the total number of particles becomes too large. Similarly, an aerosol, smoke and dust photometer manufactured by Phoenix Instrument Co. provides a count of total particles of significant size.

Condensation nuclei type instruments (described in section 3.1.1.4) may also be used to automatically and continually determine the presence of particulate matter. Particles ranging in size from 0.1 to 0.001 micron in diameter are readily detected using this technique (Ref. 23). However, because of the mode of operation, only the total quantity of particles is determined, regardless of particle size distribution. Total counts as low as 10 particles per cubic centimeter can be obtained. A sampling rate of several times per second results in essentially a continuous measurement of particulate concentration. Figure 8 shows schematically the condensation nuclei type instrument when used as a particulate detector and counter. In any one cycle, the incoming sample containing the particulate matter is drawn in through a humidifier whose purpose is to bring the sample to a 100% relative humidity condition. It is then valved into the expansion chamber where after a brief dwell period the sample is expanded rapidly to a source of regulated vacuum. The sudden expansion results in adiabatic cooling of the sample and causes the relative humidity to rise above 100%. Water will then condense on the particulate matter present. The resulting droplets soon grow to a size where they can scatter light. Also contained in the expansion chamber is a dark field optical system which produces no light to the photomultiplier phototube in the absence of condensation nuclei droplets. However, with droplets present in the chamber, light will be scattered to the phototube. The intensity of light is proportional to the number of droplets (each containing one nucleus) and to their scattering area. The output of the photomultiplier tube, after amplification, can be applied to telemetry and/or recorders. As a matter of interest, airborne bacteria can be differentiated from other particulate matter and counted using the condensation nuclei technique.



Figure 8. Condensation Nuclei Particle Detector

Identification. Quantitative identification of particulate contaminants may be accomplished by chemical analysis, petrographic analysis, immersion, differential fusion, X-ray diffraction, and combinations thereof. For example, the best method for the determination of free silica (an unlikely problem in spacecraft) requires standard chemical analyses combined with petrographic and X-ray diffraction analyses of residues at various steps in the procedure (Ref. 28). A sample size of 0.1 gm or less may be used. Petrographic, immersion, and differential fusion may be used for mineral dust analysis. X-ray diffraction may be used advantageously for the analysis of a particle mixture which may contain both metallic and non-metallic substances. Quantitative estimates of the amount of each substance present may be obtained. In combination with a recording geiger counter, the X-ray spectrophotometer can provide high accuracy for identifying crystalline type materials (Ref. 29). About a 60 mg sample is required. An electric arc type spectrophotometer also may be used for analysis. Semi-quantitative results can be obtained from samples as small as 0.05 mg. The electric arc type is advantageous for multiple compound identification in that the basic elements of the sample are disclosed; thus there are no restrictions on the kind of sample which may be analyzed. None of the above lend themselves to automated monitoring on a continuous basis.

### Instrumentation Specifications

Many of the comments on instrumentation for detecting and identifying gas and vapor contaminates also apply to instrumentation associated with particulate matter. The problem is complicated by the need to measure particle size, particle concentration in terms of weight or in terms of numbers (ideally as a function of particle size), and particle chemical composition per se. All of the foregoing are needed to provide a reliable assessment of the toxic hazard. No single instrument, either currently available or under development, can perform the required functions needed for detection and identification for the entire range of anticipated particle contaminants. Until new techniques are developed, an interim solution combining a particle counting type device, a sample gathering technique and a multi-compound identification capability is suggested. In this combination, a light scattering type photometer and counter combination would function as an early warning device by indicating that the total atmosphere particle count had exceeded the normal (and acceptable) background count. The sampling and identification capability (an impinger type device plus an electric arc type spectrophotometer for example) would then be employed to assess the probable danger of the increased particle count. By setting the automatic warning capability to initiate an alarm when minimum tolerable limits are exceeded, sufficient time should be available to accomplish the relatively time consuming sampling and identification.

One problem associated with the above approach (and probably any other, for that matter) is the determination of an acceptable threshold particle count. Particle inhalation is the usual cause of disability. Particles of 15 to 25 micron size are likely to be caught in the nasal passages or at the back of the throat. Smaller particles may impinge on the trachea or bronchi and gradually be removed by action of the cilia. Particles below five microns in size, and particularly below one micron, may enter and be retained by the alveoli where they may pass directly or indirectly into the lymph circulation. The optimum silica particle size for alveolar deposition is about one micron; for lead (on the basis of density) the optimum size would be about 0.5 micron (Ref. 27). The above would indicate that a count of all particles between approximately 5 and 0.1 micron would be a satisfactory criterion. It might be argued that the high retention of very small particles revealed by the use of the condensation nuclei type instrument, 80% retention at 0.06 micron average radius (Van Luik, F.W. Per. Comm., G.E. (1963), negates the above. However, inspection of Figure 9 reveals the large quantity of smaller particles required to be equivalent (in volume or weight) to a one micron particle. Since mass as well as number is important, the five to 0.1 micron range appears to be satisfactory.



Figure 9. Equivalent Number of Particles

Assuming a leak-tight spacecraft, numerous toxic particulate contaminants could build up to unacceptable concentration levels (assuming partial or complete failure of the contaminant control equipment). Thus all missions in excess of a few days duration should include a particulate contaminant monitoring and identification system exhibiting the following performance capabilities:

### a. Resolution

Resolve toxic particulate contaminants in the presence of the normal gases (oxygen, diluent and water vapor) which exist in the spacecraft breathing atmosphere.

### b. Sensitivity

Exhibit a sensitivity high enough to discern above the instrument background noise the threshold concentration (on the basis of particle count and/or weight) of any toxic material expected. This threshold concentration should be an order of magnitude below the unacceptable level for the particular contaminant involved. An instrument system threshold sensitivity of the order of 0.01 mg/m<sup>3</sup> with particle sizes between 5 and 0.1 microns appears desirable.

### c. Fundamental Mode of Analysis

The method of analysis should allow the identification of particle types which may be unpredicted.

### d. Sampling Rate

The time from one analysis to the next should be short enough to safely monitor the possible rapid build-up of contaminants. Thirty to sixty minutes or less appears desirable for completing one detection and identification analysis.

### e. Sample Size

The sample size must be small enough to minimize loss of spacecraft atmosphere (where the analytical technique discards it outside the vehicle).

### f. Fail Safe Characteristics

The instrumentation must indicate in some way when its data are no longer valid.

### g. Signal Output Characteristics

The output of the instrumentation system must be capable of modulating telemetry signals as well as operate on-board readouts.

h. Reliability

The mean-time-to-failure of the instrumentation including redundancy effects must be consistent with the mission length.

### i. Accuracy

Plus or minus 10% of full scale.

# j. Environmental Conditions

The instrumentation must be capable of meeting the performance requirements when subjected to the following environmental conditions or rational combination thereof:

Environment	Range
Temperature	0 to 150 <sup>0</sup> F
Pressure	ambient to vacuum
Radiation	5 REM max. normal, 100 REM max. emergency
Humidity	0 to 100% RH
Acoustics	135 db between 40 and 9600 cps
Acceleration	20 g along each of three mutually perpendicular axes
Vibration	<sup>+</sup> 2.3 g's, 20 to 50 cps 0.018 in. double amplitude; 50-112 cps 11.4 g's; 112-2000 cps (along each of three mutually perpen- dicular axes)
Impact Shock	20 g's for 10 milliseconds along each of three mutually perpen- dicular axes.

### DISCUSSION

Preparation of lists of materials presently used or proposed for use in spacecraft construction is in progress, but not yet completed. Data on quantities of materials used or proposed are not available. Steps should be taken to compile these data for current system projects and to insure that such data are compiled in future manned spacecraft programs. The lists in the appendices to this report include, as best as can be determined, approximately one-half of all the materials expected to be used in the habitable portion of Apollo, Mercury, Gemini, and Dyna-Soar spacecraft.

The detection and identification of atmosphere contaminants as generated by mechanical, thermal and other stresses may be categorized into two areas: gases and vapors and airborne particulate matter. For gases and vapors, the most significant generation mechanisms appear to be evaporation and thermal degradation. The study of literature on the thermal degradation of elastomers shows that this area of investigation has been reasonably well covered at temperatures above 200°C. There is, however, a lack of information on off-gassing at ambient temperatures. It should be noted that deductions based on the chemical formula of the material can be very unreliable. A comprehensive study of off-gassing under ambient spacecraft conditions of materials likely to be used in manned spacecraft should be initiated. The study should also include the effects of a pure oxygen atmosphere as well as other non-standard atmospheres that may be proposed in the future. A similar situation exists in the area of radiation degradation of elastomers. Both quantity and rate of generation of off-gassing products should be determined. In addition to providing information for identification and detection, this will permit an assessment of the danger of included specific quantities of a particular compound in a given spacecraft. If the quantity or rate of off-gassing will not exceed tolerable limits for a particular operating environment, then no toxic problem exists for that particular contaminant for a given spacecraft. In contrast to the arbitrary exclusion of any substance which may off-gas toxic contaminants, quantity and rate knowledge permits greater flexibility in equipment design.

No single instrument currently exists which exhibits the versatility and performance characteristics required to serve as a monitor for toxic trace gases and vapors during all missions. The variety of materials planned for use on current spacecraft programs and the degradation products therefrom is imposing. Many of these materials can be eliminated, particularly for missions of relatively short duration, by extensive ground testing of the complete operating system. For long duration missions, it would appear unlikely that the long term interactions of materials, off-gassing products, and environment could be duplicated by ground testing. In any case, man himself is an excellent generator of toxic contaminants. Thus, for other than short missions, monitoring instrumentation must be capable of the detection and identification of a wide variety of toxic contaminants, some of which may not have been anticipated. Threshold sensitivity must also be in the parts per billion rather than in the parts per million range in order to detect and identify contaminants at concentrations significantly below tolerable limits. A multiple gas detector(s) in combination with a trace gas concentration and separation technique appears to be the best available approach to the instrumentation requirements for long term missions. The type of detector used should be one which can detect the presence of an unexpected contaminant.

Particulate matter may be generated by several mechanisms such as mechanical abrasion and recondensation. Many of the comments on gases and vapors are applicable to particulate matter type contaminants. Information on both quantity and rate of generation are needed to permit a realistic selection of spacecraft materials and contaminant control equipment. For long duration missions, it is unlikely that flight conditions can be duplicated during ground testing to a degree which would insure no unexpected particulate type contaminants during later phases of the mission. Thus, for other than short missions, instrumentation for monitoring of particulate matter type contaminants must be capable of the detection and identification of a wide variety of contaminants, some unexpected, and at concentrations significantly below tolerable limits. No single instrument is available to both detect and identify. Detection may be accomplished on a continuous automatic basis by use of a light scattering type of photometer and counter. Either total particle count or count for discrete sizes over the entire particle size range of hygienic interest can be obtained, the latter providing the best data for assessing the potential toxic hazard. Identification is comparatively complicated. A sampling means must be used to gather a sample of sufficient mass to permit analysis. An electric arc type spectrophotometer may be used to establish the chemical identification of the particles. Since identification is time consuming as compared to detection, a suggested approach is to use the detecting portion of the system as an early warning capability followed by the identification procedure when threshold concentration limits are exceeded.
In summary, for long duration missions, the generation of a large variety of toxic contaminants, both predicted and unpredicted, can be assumed. Information on quantity and rate of generation of these contaminants is needed to permit a realistic appraisal of their effect in a particular application. Development of new techniques for the detection and identification of toxic contaminants, gases and vapors and particulate matter, is required if useful contaminant monitoring is to become a practical reality for spacecraft applications.

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## APPENDIX A

### APOLLO COMMAND MODULE MATERIALS LIST

This is a list of materials which are being considered for the Command Module of the Apollo spacecraft as compiled by the Life Sciences Group of the North American Aviation Corp. The list is estimated to be approximately 50% complete.

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6020A
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6293P
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6020G
Adhesive	Silicone	ï				Stabilization & Control System	Dow Corning Q-30079
Banding Strip						Stabilization & Control System	A.J. Gerrard & Co.
Adhesive	Epoxy-Amine TiO2 Filler	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	225 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell Type 6020M & Minnesota Mining
Adhesive	Epoxy-Amine	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	350 <sup>0</sup> F	Stabilization & Control System P1,2:Q1, 2	Minneapolis Honeywell Type 6293G
Adhesive Epoxy Cast Resin	Epoxy-Amine Ca CO <sub>3</sub> Filler	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell, Aero 6020Q, AMS 3740
Adhesive	Epoxy	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	250 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Rubber & Asbestos Corp.

APPENDIX A

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MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Nitrile	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	250 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Minnesota Mining
Adhesive	Polyamide	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	
Adhesive	Phenolic Glass	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	
Adhesive	Rubber					Stabilization & Control System	Minnesota Mining EC870
Adhesive						Stabilization & Control Syrtem	Minnesota Mining EC847
Adhesive						Stabilization & Control System	Dow Corning 6851A A-4000 ADH
Fluid	Trifluoro- chloroethylene	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	
Primer Coating	Gray Vinyl					Stabilization & Control System	Amercoat Corp. Amercoat 33
Primer Coating	Epoxy Strontium- Chromate	No	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	

		HERM. SEALED	NORM. OPER. TEMD	MAX. OPER. TEMD	MAX. FAIL	LOCATION	MANUFACTURER
MATERIAL	COMPOSITION	(YES-NO)	TEMP	AWAL	-AWAT	(ULUULUUU)	& TRADE NAME
Laminate	MIL-P-18177	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	350 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	
Laminate	Glass Epoxy					Stabilization & Control System	Formica FF-95
Laminate	Glass Epoxy					Stabilization & Control System	General Electric Texto 11559
Laminate	Glass Epoxy MIL-P-18177					Stabilization & Control System	National Vulcanized Fiber Co. G-11-861
Laminate	Glass Epoxy					Stabilization & Control System	Synthane G-11
Laminate	Nylon Phenol Laminate					Stabilization & Control System	Synthane N-1
Laminate	Glass Epoxy					Stabilization & Control System	Minnesota Mining Lamicord 6096
Enamel	Gray Epoxy					Stabilization & Control System	Glidden SE-7077
Enamel	Black Epoxy					Stabilization & Control System	Glidden 287-B-505
Varnish					÷	Stabilization & Control System	Maas & Waldstein Y 170 A
Enamel	Epoxy Polyamide	No	150 <sup>0</sup> F	180 <sup>0</sup> F		Stabilization & Control System P1, 2:Q1, 2	D. J. Peterson

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Enamel	Ероху	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q1, 2	
Enamel	Brown Epoxy					Stabilization & Control System	D. J. Peterson Poly-EP color 30279
Enamel	Brown Epoxy					Stabilization & Control System	D. J. Peterson Poly-EP Color 30450
Enamel	Gray Wrinkle					Stabilization & Control System	Glidden RGL-212900
Enamel	Gray Wrinkle					Stabilization & Control System	Glidden MGL-9577
Enamel	Black Wrinkle					Stabilization & Control System	Glidden RGL-2-1204
Laminate	Glass Epoxy					Stabilization & Control System	Continental Diamond Co. GB-28-E-FR
Glass	Copper Clad Glass Epoxy	No	150 <sup>0</sup> F	180 <sup>0</sup> F	350 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	National Vulcanized Fiber Co. G-11-861-1
Glass	Copper Clad Glass Epoxy	No	150 <sup>0</sup> F	180 <sup>0</sup> F	350 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Synthane G-11

LOCATION MANUFACTURER (COORD) & TRADE NAME	Stabilization Class BA1 & Control System	& Control System	Stabilization Varflex Corp. & Control System Varflow 121	Stabilization Stevens Paper Mills & Control System	Stabilization Minnesota Mining & Control System 38	Stabilization Minnesota Mining & Control System 3	Stabilization Minnesota Mining & Control System 56	Stabilization Minnesota Mining & Control System 5	Stabilization Permacel EE 3504 & Control System	Stabilization Western Felt & Control System	Stabilization Dupont Mylar & Control System P1, 2:Q1, 2	
MAX. FAIL TEMP.											300 <sup>0</sup> F	
MAX. OPER. TEMP.											180 <sup>0</sup> F	
NORM. OPER. TEMP.											150 <sup>0</sup> F	
HERM. SEALED (YES-NO)											No	
COMPOSITION	Acrylic Resin Fiberglass MIL-I-3190B	ACTVIIC RESIL	Fiberglass Vinyl		MIL-I-15126	MIL-I-15126	Polyester	Polyester	Polyester		Polyester	
MATERIAL	Glass	2005 	Tubing	Paper (Ungummed)	Paper (Crepe)	Electrical Paper Tape	Tape	Tape	Tape	Felt	Film	

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	MAX. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Foam	Urethane					Stabilization & Control System	Nopco Chemical Co. G 306
Lubricant	Silicone Oil					Stabilization & Control System	General Electric Versilube F 50
Lubricant	Halogenfluoro- Carbon					Stabilization & Control System	Minnesota Mining Kel F No. 1
Grease	MIL-I-8660					Stabilization & Control System	Dow Corning DC4
Molding Compound	Polyamide	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Dupont ZYT 113 NC 10
Molding Compound	MIL-P-14	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	400 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	
Molding Compound	Epoxy-Amine	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	350 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Fiberite
Molding Compound						Stabilization & Control System	Durez
Molding Compound	Polyamide, Black					Stabilization & Control System	Dupont ZYT 101BK-09
Gasket	Neoprene-Cork MIL-G-6183					Stabilization & Control System	Armstrong Cork NC 709

		HERM. NORM.	MAX.	MAX.		
MATERIAL	COMPOSITION	SEALED OPER. (YES-NO) TEMP.	OPER. TEMP.	FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
insert Paper					Stabilization & Control System	Carpenter Paper Co.
Potting Compound	Urethane				Stabilization & Control System	Minneapolis Honeywell, 3645
Potting Compound	Silicone Rubber				Stabilization & Control System	Dow Corning RTV-501 Silastic
Sealing Compound	MIL-S-8516				Stabilization & Control System	Product Research Co. PR 1201Q
Sealing Compound	MIL-S-8516				Stabilization & Control System	Coast Pro-Seal Pro-Seal 727
Sealing Compound					Stabilization & Control System	Minneapolis Honeywell, Aero 7083C
Sealing Compound	Silicone Rubber				Stabilization & Control System	General Electric RTV-90
Screw Sealants					Stabilization & Control System	American Sealants Loctite Grade A Grade C Grade D
Gasket (Conductive)					Stabilization & Control System	Connecticut Hard Rubber
Silicone Sponge Rubber	AMS 3195				Stabilization & Control System	Connecticut Hard Rubber CLR10470
Fairprene Rubber					Stabilization & Control System	Dupont N5580HA Fairprene

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MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Silicone Rubber						Stabilization & Control System	Dow Corning SUST S-2007
Fluorinated Rubber	MIL-R-25897					Stabilization & Control System	Minnesota Mining Fluorol
Fluorinated Rubber	MIL-R-25897					Stabilization & Control System	Dupont Viton A
Screening Ink						Stabilization & Control System	Naz Dar Type 5511 Type 802 Type DL112
Screening Ink						Stabilization & Control System	Markem Machine Co. HM 7132
Screening Ink						Stabilization & Control System	General Printing WE Verm 44 WE Yellow 44 WE Yellow 43
Thermoplastic	MIL-P-8184					Stabilization & Control System	Rohm & Haas Plex 55 Acrylic
Thermoplastic	MIL-P-5435B					Stabilization & Control System	Rohm & Haas Plexi II-UVA Acrylic
Rod & Strip	Polyamide					Stabilization & Control System	Polymer Corp. Type ZYT 101
Tying Cord	Polyamide MIL-T-713					Stabilization & Control System	Gudebrod Bros. Style 18 Type P Class 2
Tying Cord	Dacron MIL-F-8261					Stabilization & Control System	Western Fishing Line Co. 50 DOF 16A

		HERM. SFALED	NORM. OPER.	MAX. OPER.	MAX. FAIL	LOCATION	MANUFACTURER
MATERIAL	COMPOSITION	(YES-NO)	TEMP.	TEMP.	TEMP.	(COORD)	& TRADE NAME
Leadwire	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type E
Leadwire	Teflon MIL-W-16878					Stabilization & Control System	Hitemp Wire & Cable Co. Type E
Leadwire	Copper MIL-W-3861	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	QPL 3861
Rod & Bar	Teflon					Stabilization & Control System P1, 2:Q 1, 2	Polymer Corp.
Wire, Teflon Jacketed	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type E
Wire, Teflon Jacketed	Teflon MIL-W-16878					Stabilization & Control System	Hitemp Wire & Cable Co.
<b>Teflon Sheet</b>	Teflon					Stabilization & Control System	Carmer Indst.
Tubing	Wrap Teflon	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	500 <sup>0</sup> F	Stabilization & Control System P1, 2:Q1, 2	Hitemp Wire & Cable Co.
Tubing	Wrap Teflon	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	500 <sup>0</sup> F	Stabilization & Control System P1, 2:Q 1, 2	American Super Temp.
Insulation	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type EE

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MANUFACTURER & TRADE NAME	Hitemp Wire & Cable Co. Type EE	Hitemp Wire & Cable Co. Polymer Corp.	Irvington Varnish & Insulator 3022 Natvar Corp.	Ray Chem Ray Clad Thermofit Simi-Rigid	Raychem Ray Clad Thermofit RNF	Suprenant Surok	Minnesota Mining Kel-F	Fluoro-Chem Co. FS Fluorolub	Insulation Mfg.	Carmer Instd. Cadillac Plastic Kel-F
LOCA TION (COORD)	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System P1, 2:Q 1, 2	Stabilization & Control System				
MAX. FAIL TEMP.		500 <sup>0</sup> F			250 <sup>0</sup> F					
MAX. OPER. TEMP.		200 <sup>0</sup> F			200 <sup>0</sup> F					
NORM. OPER. TEMP.		170 <sup>0</sup> F			170 <sup>0</sup> F					
HERM. SEALED (YES-NO)		Yes			Yes					
COMPOSITION	Teflon MIL-W-16878	Extruded Teflon AMS 3654	Vinyl MIL-I-7444	Irradiated Olefin MIL-I-7444	Irradiated Olefin AMS 53633	MIL-W-16878			Mylar	Polyester AMS 3650
MATERIAL	Insulation	Tubing	Tubing	Tubing	Tubing	Teflon & Mylar Insulated Wire	Thermoplastic	Thermoplastic	Film	Thermoplastic

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		HERM. SEALED	NORM. OPER.	MAX. OPER.	MAX. FAIL	LOCATION	MANUFACTURER
MATERIAL	COMPOSITION	(YES-NO)	TEMP.	TEMP.	TEMP.	(COORD)	& TRADE NAME
ermosetting	Di-Alylphthal MIL-M-19633					Stabilization & Control System	MESA Plastics Type GDI Class 30
i-Seize Compoun	d MIL-A-907B					Stabilization & Control System	Armite Labs Leadplate 250
ıminum	AMS 4120	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
ıminum		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Kaiser Alcoa Reynolds
ıminum	AMS 4001	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
ıminum	AMS 4037	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
ımina						Stabilization & Control System	Minneapolis Honeywell, G.V.
odize-Hard Iminum						Stabilization & Control System	
odize-Hard Iminum						Stabilization & Control System	
odize-Blue ed Aluminum	MIL-A-8625					Stabilization & Control System	Type II

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Anodize Brown Dyed Aluminum	MIL-A-8625					Stabilization & Control System	
Aluminum	QQ-A-601	No	150 <sup>0</sup> F	180 <sup>0</sup> F		Stabilization & Control System P1, 2: Q 1, 2	Alcoa
Aluminum	QQ-A-601	No	150 <sup>0</sup> F	180 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Aluminum	QQ-A-318	No	150 <sup>0</sup> F	180 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Beryllium Copper	QQ-C-530	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	
Beryllium		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2:Q 1, 2	
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Nameplate						Stabilization & Control System	C&H Supply Co. Metal-Cal, Foil, Adhesive Backing
SN Plate over CU plate						Stabilization & Control System	
Shielding	Tin & Copper	·				Stabilization & Control System	Belden Co.
Cadmium Plating						Stabilization & Control System	
Solder						Stabilization & Control System	
Solder	60/40 58 core 50/50 60/40					Stabilization & Control System	Kester Solder Co.
Solder	60/40					Stabilization & Control System	Alpha Metals
Solder Flux						Stabilization & Control System	Kester Solder Co.
Steel	Chromium Nickel Iron AMS 5688					Stabilization & Control System	
Steel						Stabilization & Control System	U.S. Steel
Steel	AMS 5640	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System	Crucible

APPENDIX A (Cont'd)

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MATERIAL NORM MAX. TEMP. LOCATION TEMP. TEMP. TEMP. MAX. TEMP. LOCATION TEMP. MAXUTACTURING   Steel AMS 5610 TEMP. TEMP. TEMP. COORDI) & TRADE NAM   Steel AMS 5610 EXEMPTION Stabilization Curcubie Curcubie   Steel AMS 5610 Exemp. Stabilization Curcubie Curcubie   Steel Control System Control System Control System Control System Comp. 303   Steel QQ-S-763 ACCATION Stabilization Crucibie Control System Control	<b>ER</b>										
MATERIAL COMPOSITION HERM. SEALED OPER. REAL. MAX. TEMP. MAX. TEMP. MAX. (COODD)   Steel AMS 5610 TEMP. TEMP. TEMP. (COODD)   Steel AMS 5610 TEMP. TEMP. CONTOL (COODD)   Steel AMS 5610 AMS 5610 EAL-IDD EAL-IDD EAL-IDD EAL-IDD EAD   Steel AMS 5610 AMS 5610 EAL-IDD EAL-IDD EAD </td <td>MANUFACTUF &amp; TRADE NAN</td> <td>Crucible</td> <td>Crucible Comp. 301 Comp. 302 Comp. 304</td> <td>Crucible</td> <td>Crucible</td> <td>C.A. Roberts</td> <td></td> <td>Enterprise Wire Co.</td> <td>Warren</td> <td>Crucible Stainless 88</td> <td>Central Steel &amp; Wire Co.</td>	MANUFACTUF & TRADE NAN	Crucible	Crucible Comp. 301 Comp. 302 Comp. 304	Crucible	Crucible	C.A. Roberts		Enterprise Wire Co.	Warren	Crucible Stainless 88	Central Steel & Wire Co.
MATERIALCOMPOSITIONHERM. SEALEDNORM. NORM. SEELEDMAX. TEMP.MAX. TEMP.SteelAMS 5610FES-NO)TEMP. TEMP.TEMP. TEMP.MAX. TEMP.MAX. TEMP.SteelAMS 5610COPOSITIONCOPOSITIONTEMP. TEMP.MAX. TEMP.MAX. TEMP.MAX. TEMP.SteelQQ-S-765QQ-S-765PPPSteelQQ-S-766PPPPSteelQQ-S-766PPPPSteelQQ-S-766PPPPSteelQQ-S-766PPPPUriceChronium NickelYes170°FPUriceSteelPPPPLeadwireCopper Tin QQ-W-343 Type SYes170°F200°FSteelMIL-S-5059No150°F180°F	LOCATION (COORD)	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System	Stabilization & Control System P1, 2: Q1, 2	Stabilization & Control System	Stabilization & Control System P1, 2: Q1, 2	Stabilization & Control System	Stabilization & Control System
MATERIALCOMPOSITIONHERM. SEALEDNORM. OPER. TEMP.MAX. SEALEDSteelAMS 5610TEMP.OPER. TEMP.OPER. OPER.SteelAMS 5610AMS 5610TEMP.OPER. OPER.SteelQQ-S-766APS-766APS-766APS-766SteelQQ-S-766APS-766APS-766APS-766SteelQQ-S-766APS-766APS-766APS-766SteelQQ-S-766APS-766APS-766APS-766SteelChronium NickelYes170°F200°FUrieSteelYesYes200°FSteelMI-S-5059No150°F200°FSteelMI-S-5059No150°F200°FSteelMI-S-5059No150°F200°F	MAX. FAIL TEMP.										
MATERIALCOMPOSITIONHERM. SEALEDNORM. OPER. TEMD.SteelAMS 5610TEMD.SteelAMS 5610TEMD.SteelQQ-S-763SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelPologeSteelYesSteelNoSteelMIL-S-5059SteelNoSteelSteelSteelMIL-S-5059SteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteelNoSteel <td< td=""><td>MAX. OPER. TEMP.</td><td></td><td></td><td></td><td></td><td></td><td>200<sup>0</sup>F</td><td></td><td>200<sup>0</sup>F</td><td>180<sup>0</sup> F</td><td></td></td<>	MAX. OPER. TEMP.						200 <sup>0</sup> F		200 <sup>0</sup> F	180 <sup>0</sup> F	
MATERIALCOMPOSITIONHERM. SEALEDSteelAMS 5610YES-NO)SteelAMS 5610YES-NOSteelQQ-S-768YesSteelQQ-S-766YesSteelQQ-S-766YesSteelChromium NickelYesVireSteelYesUradwireSteelYesVireSteelYesVireSteelYesVireSteelYesVireSteelYesVireSteelYesVireYesVireYesSteelYesVireYesSteelYesSteelYesVireYesSteelMIL-S-5059SteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYesSteelYes	NORM. OPER. TEMP.						170 <sup>0</sup> F		170 <sup>0</sup> F	150 <sup>0</sup> F	
MATERIALCOMPOSITIONSteelAMS 5610SteelAMS 5610SteelQQ-S-765SteelQQ-S-766SteelQQ-S-766SteelQQ-S-766SteelSteelSteelQQ-S-766SteelSteelSteelQQ-S-766SteelSteelSteelQQ-S-766SteelSteelSteelQQ-S-766SteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelSteelMIL-S-5059SteelSteelSteelSteel	HERM. SEALED (YES-NO)						Yes		Yes	No	
MATERIAL Steel Steel Steel Steel Steel Leadwire Steel	COMPOSITION	AMS 5610		QQ-S-763	ଭ୍ୟ-S-766		Chromium Nickel Iron AMS 5688	Steel	Copper Tin QQ-W-343 Type S	MIL-S-5059	
	MATERIAL	Steel	Steel	Steel	Steel	Steel	Steel	Wire	Leadwire	Steel	Steel

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Brass	AMS 4505					Stabilization & Control System	Anaconda American Brass
Brass	AMS 4610	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	Chase Brass & Copper
Brass (Wire)	QQ-W-321	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	
Copper						Stabilization & Control System	Anaconda American Brass
Copper	Copper, Lead	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	
Phos Bronze					Ň	Stabilization & Control System	Miller & Co.
Magnesium	AMS 4120					Stabilization & Control System	Hitchcock
Magnesium						Stabilization & Control System	Dow Chemical Co.
Resistance Wire	88% Copper	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	500 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	W.B. Driner
Magnetwire	Copper, Polyvinyl Acetate MIL-W-583 Class 105 Type T2	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	221 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	Rea Magnet Wire Co. QPL 583

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MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Magnetwire	Nylon, Urethane Copper	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	268 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Copper Products Types: T4 B Single Nylese B2 Heavy Nylese
Magnetwire						Stabilization & Control System	Phelps Dodge Copper Products
Magnetwire						Stabilization & Control System	Rea Magnet Wire Co. Types T4 B Single Nylsol B2 Heavy Nylsol L2 Isonel-BF
Magnetwire	Polyester Copper	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	$311^{0}F$	Stabilization & Control System P1, 2: Q1, 2	Hitemp Wire & Cable Co. Types: L2- Thermisterl
Magnetwire						Stabilization & Control System	Hitemp Wire & Cable Co. SFX Type K
Magnetwire	Copper, Polyvinyl Acetate	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	221 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Copper Products
Magnetwire	Double ML Polyamide Copper	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	482 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Hitemp Wire
Magnetwire						Stabilization & Control System	Phelps Dodge Copper Products B3 Nylese
Wire	Nickel					Stabilization & Control System	W.B. Driner Grade A

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MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Chrome Treatment	MIL-C-5541					Stabilization & Control System	Amchem Alodine 1200A
Clear Chrome Treatment						Stabilization & Control System	Amchem Alodine 1000L
Dumet						Stabilization & Control System	General Electric
Nickel Iron Alloy	AMS 7705	Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	
Nickel Iron Alloy		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	
Bismuth Tin Alloy		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F	281 <sup>0</sup> F	Stabilization & Control System P1, 2: Q1, 2	
Silver Paste		ves	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	Emerson Cuming
Iron		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	Armco
Cobalt Iron Alloy		Yes	170 <sup>0</sup> F	200 <sup>0</sup> F		Stabilization & Control System P1, 2: Q1, 2	
Gold Plating						Stabilization & Control System	Minneapolis Honeywell, Boston
Cadmium Plating	QQ-P-416		•			<sup>r</sup> 1, 4: 41,4	
Hae % Thin							

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Conductive Epoxy					Telecommunica- tions System	Chromerics 360-18
Adhesive	Conductive Resin	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Chromerics356-18
Adhesive	One-Part Modified Epoxy Resin	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> ғ		Telecommunica- tions System	Minnesota Mining EC 2186
Adhesive	Heat Conductor					Telecommunica- tions System	Chromerics 356-16
Adhesive	Silicone Rubber					Telecommunica- tions System	Dow Corning Corp. RTV-140
Adhesive	Silicone Rubber	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dow Corning Corp. RTV-731
Ceramo-Plastic		Yes & No	149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	Mycalex Supremica
Ceramic	High Alumina MIL-1-10					Telecommunica- tions System	Centralab Body 208
Cat-L-Ink		Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Atlas Silkscreen Corp.
Anti-Friction	90% Molydisulfide 10% Graphite with Phenolic Resin Binder					Telecommunica- tions System	Electrofilm Inc. 4396
Adhesive	Silicone Rubber	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dow Corning Corp. RTV-731

	-	HERM.	NORM.	MAX.	MAX.		
MATERIAL	COMPOSITION	VES-NO)	OPER. TEMP.	OPER. TEMP.	FAIL TEMP.	LOCATION (COORD)	MANUFACTURER
Ceramo-Plastic		Yes & No	149 <sup>0</sup> F	$257^{0}F$		Telecommunica-	© I RADE NAME Mycalex Supremica
Ceramic	High Alumina MIL-I-10					tions System Telecommunica-	Centralah Body 208
Cat-TTnb			¢			tions System	
All-1-120	·	Yes & No	$104^{0}F$	167 <sup>0</sup> F		Telecommunica- tions System	Atlas Silkscreen Corp.
Anti-Friction Coating	90% Molydisulfide 10% Graphite with Phenolic Resin Binder					Telecommunica- tions System	Electrofilm Inc. 4396
Flexibilizer for Hysol 4183	Epoxy	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica-	Dow Chemical Co.
<b>Casting Resin</b>	Epoxy	Yes & No	104 <sup>0</sup> E	1670 -		lianske errore	Exp. Resin X2673-2
•				- - - 1		Telecommunica- tions System	Houghton Labs. Hysol 4183 with
Foam	MIL-C-80872	Yes & No	104 <sup>0</sup> բ	16705		  	Hardner 3469
53 C E			н 2	- - - -		Telecommunica- tions System	Nopco Chemical Co. Lockfoam A206
		Yes & No	149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	Corning Glass 7940
Highly Thermal Conductive Com- pound for Semi- Conductor	Grease-Like Silicone					Telecommunica- tions System	Dow Corning Corp. C-2-0168
Lubricant	Silicone Fluid	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup>		Telecommunica- tions System	General Electric Versilube F 50

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
icant						Telecommunica- tions System	General Electric Versilube G300
ganic Bonded Film Lubricant	Molydisulfide Graphite with Sodium Silicate Binder	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Alpha-Molykote Corp. Molykote X-15
tic Laminate	Glass Cloth- Epoxy Resin Binder MIL-P-18177	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Continental Diamond Co. Fiber Flame Retardant G-10
ber Like erial	Freeze Resistant Neoprene MIL-A-3005	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dupont Mylar
ber Like erial	Silicone Rubber	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dow Corning Corp. RTV-521
ber Like erial	Silicone Rubber	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dow Corning Corp. RTV-S-5313 RTV-S-5314 with 50% DC-200 Oil
cone Gel	Silicone Resin	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dow Corning Corp. Sylgard 182
ermoplastic	Monochlorotri- fluoroethylene MIL-P-55028B					Telecommunica- tions System	Minnesota Mining Kel-F
ermoplastic	Polyethylene Terephthalate MIL-I-631	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dupont Mylar

		HERM. SEALED	NORM.	MAX.	MAX.		
MATERIAL	COMPOSITION	(YES-NO)	TEMP.	TEMP.	TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Thermoplastic	Irradiated Polyolefin					Telecommunica- tions System	Raychem
Thermoplastic	Polyamide	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> ғ		Telecommunica- tions System	Dupont Nylon 301
Thermoplastic	Polystyrene MIL-P-77B	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Polypenco Q200.5
Thermoplastic	High Polymer of Tetrafluoroethy- lene MIL-P-19468	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Dupont Teflon
Thermoplastic							
Teflon Jacketed Wire	0	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> Fto 2120F		Telecommunica- tions System	Suprenant 4394000 414900
Nickel Coated Wire	Alloy 63 Nickel Coated	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F to 212 <sup>0</sup> F		Telecommunica- tions System	Suprenant No. 26 & Smaller Type Wire
Ceramic	Beryllium Oxide	Yes & No	149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	National Beryllia Co.
Thermosetting	Diallyl Phthalate Mineral Filled					Telecommunica- tions System	Durez
Thermosetting	Mineral Filled Phenolic MIL-M-14E ''Bakelite''					Telecommunica- tions System	Durez

			APPENDI	X A (Cont'	'd)		
MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Thermosetting	Epoxy, Filled 1:1 by Weight with Quartz Diethylam- inopropylamine Catalyst	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Shell Chemical Corp. EPON 828 with Filler Curing Agent A
Steel	302 Stainless QQ-S-763B	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommuníca- tions System	Armco Steel
Steel	17-4PH Stainless	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Armco Steel
Steel	440 Stainless			41 1		Telecommunica- tions System	Armco Steel
Aluminum	Aluminum 6061	Yes & No	75 <sup>0</sup> F	252 <sup>0</sup> F		Telecommunica- tions System	Alcoa
Aluminum	Aluminum 5052 QQ-A-318Bb	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Alcoa
Aluminum	Aluminum 2024	Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Alcoa
Aluminum 356 Casti	ßu					Telecommunica- tions System	Alcoa
Beryllium Copper		Yes & No	104 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	Beryllium Corp.
Copper		Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F	ч Мар	Telecommunica- tions System	Anaconda Chase
Gold		Yes & No	75 <sup>0</sup> F	252 <sup>0</sup> F		Telecommunica- tions System	Sel Rex Technic

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Gold		Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Sel Rex Technic
Indium		Yes & No	75 <sup>0</sup> F to 149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	Indium Corp.
Nickel		Yes & No	75 <sup>0</sup> F to 149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	International Nickel Corp.
Phosphorous Bronze		No	75 <sup>0</sup> F	252 <sup>0</sup> F		Telecommunica- tions System	American Brass
Silver		No	75 <sup>0</sup> F	252 <sup>0</sup> F		Telecommunica- tions System	American Platinum
Silver		Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	American Platinum
Solder	Type 60/40	Yes & No	75 <sup>0</sup> F to 149 <sup>0</sup> F	257 <sup>0</sup> F		Telecommunica- tions System	Kester Federated
Rhod		Yes & No	104 <sup>0</sup> F	167 <sup>0</sup> F		Telecommunica- tions System	Sel Rex Technic Inc.
Nickel & Tin						Telecommunica- tions System	Sel Rex Technic Inc.

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	MANUFACTURER & TRADE NAME	At request	At request	At request
	LOCATION (COORD)			
	MAX. FAIL TEMP.			
(Cont'd)	MAX. OPER. TEMP.			
PENDIX A	NORM, OPER, TEMP.		· ·	
AP]	HERM. SEALED (YES-NO)	No	No	No
	COMPOSITION	Silicon .5 to 1.2 Iron 1.0 Copper 3.9 to 5.0 Manganese .4 to 1.2 Magnesium .2 to .8 Chromium .1 Zinc .25 Titanium .15 Other .15 Other .15 Max05 for each) Aluminum Remainder	Silicon .4 to .8 Iron .7 Manganese .15 to .4 Magnesium .15 Chromium .8 to 1.2 Zinc .25 Titanium .15 Other .15 Other .15 Max05 for each) Aluminum Remainder	
	MATERIAL	2014-T6 (QQ-A-327)	6061-T6	Butyl

# APPENDIX B

# PHYSICAL PROPERTIES OF NON-METALLIC MATERIALS FOR MANNED SPACE VEHICLES

This material is excerpted from McDonnell Aircraft Corporation report 6792, revised April 1963, "Physical Properties of Non-Metallic Materials for Manned Space Vehicles." Report 6792 has been prepared to establish maximum use temperatures for non-metallic materials to be used in the inhabited area of spacecraft. The indicated temperature limits are based upon laboratory tests using 100% oxygen atmosphere at 5 PSI absolute for 3-24 hours continuous usage without producing irritating or obnoxious odors. Toxicity vs. temperature limits are not based on actual tests but were compiled as a result of odor tests and a basic knowledge of chemical and thermal properties. In most cases the maximum temperatures shown were established by tests because of a current operating temperature. Some, in fact most of the materials listed will probably pass a higher temperature.

The charts are for use as guides to Design Engineers concerned with the selection of non-metallic or non-ceramic materials. In most cases materials are listed by popular chemical names. It is recognized that some Design Personnel may not be familiar with the popular chemical names; it is therefore recommended that "MIL Spec" materials, "MMS" (MAC Material Specifications) materials, "AMS" (Aeronautical Material Specification) material or trade name materials be identified chemically before consulting the charts.

The charts do not establish temperature limits for mechanical or electrical properties. Most of the materials can withstand much higher temperatures than those indicated. In selection of materials, it is desirable always to choose the highest temperature material available since higher temperature materials have more possibility of passing the odor and toxicity tests. Selection of lubricants and fluids must be based on whether the parts or systems are open within the cabin.

Enclosure 1 is included, <u>Contaminants Recovered from Capsule Atmosphere of</u> <u>Mercury Flights</u> (NASA Report), which presents the contaminants and the results in parts per million and actual weight in milligrams. Quantitative measurements were made by desorbing activated carbon which collected gases from the capsule atmosphere of Mercury flights 6, 7 and 8. In general the table shows that a safe atmosphere was maintained in the spacecraft and that odor tests conducted for use in the Mercury Spacecraft were an effective means of predicting the safety level of the atmosphere under operating conditions.

	OLFACTORY AND NON-1	OXIC PROPERTIES OF NON	-METALLIC MATERIALS 1	N 100% OXYGEN AT 5	PSIA POR 3-24 HOURS
	NOTES: MA CC M	tallic Materials are r mditions and temperatu terial not tested at ]	act shown, but are con area ladicated on this L600F	sidered safe for us chart.	e under the
Material	Source or Manufacturer	Specification	Maximum temperature   for unobjectionable odor	faximum temperature for non-toxic properties	Remerks
RUBBER MTERIAL (ALL FORMS) Reoprene (Sponge) Reoprene		MIL-R-6855, CLAMS II ANS-3197	250 <b>97</b> 250 <b>97</b> 2509 <b>7</b>	250 <b>07</b> 250 <b>07</b> 250 <b>07</b>	Bendix Pigmy Connector vith Neoprene insert.
Buns. N Buns. N Buns. N Buns. N	Parker Plastic & Rubber Products Co. Stillman Rubber Co.	SAE 1208, Class I MIL-P-5315 MIL-P-5315 MIL-P-25732	160 <del>07</del> 160 <del>07</del> 16092	160 <b>°F</b> 160 <b>°F</b> 250 <b>°F</b> 80 <b>°F</b>	No. 1011-10 No. 457 Stillman compound 3R 832-75 (Produced Strong Odor at 250 <sup>9</sup> F)
Silicome Silicome Silicome Silicome	Dow Corning Corp. Dow Corning Corp.	ANS- 3345 ANS- 3345	2500F 2500F 3600F	250 <b>07</b> 3600 <b>7</b> 1600 <b>7</b>	Silestic S-2007. No. 9711
Polyurethane Polyurethane	Dayton Rubber Co. Minnespolis-Honeywell Co.		160 <sup>0</sup> F 160 <sup>0</sup> F	40091 40091	Staroom U543 Aeroflex M.S. 7083
Viton A Viton A	E.I. Dupont Co.		1600F 2000F	160 <b>0F</b> 200 <sup>0</sup> F	Splice inserts.
Netural Rubber Natural Rubber Natural Rubber Natural Rubber	Stillman Rubber Co. Stillman Rubber Co. Seamless Rubber Co. Davol Co.	Commercial Commercial Commercial	160 <b>07</b> 160 <b>07</b> 80 <b>07</b> 80 <b>07</b>	4008 1009 1009 1009	Stillman compound No. SR 221-40. Stillman compound No. SR 222-60. Seamless Rubber compound No. RD-11;4. Davol Co. Type 5-9518 squeeze bulb, unsatisfactory at 125 <sup>0</sup> F
Fairprene Rubber	E.I. Mupont Co.	Commercial	16007	loor	AiResearch Part No. 10-150949-8 Casket
Rubber Base Foam	B.F. Goodrich Chemical Co.	Commercial	160 <b>0F</b>	160ºF	
Rubber Covered Cord(Flexible	Reiland	Commercial	160 <sup>0</sup> F	160°F	M.A.C. Part No. 45-81099, Heiland No. 302511.
Elastic Hose	Arbelet	Connerical	160 <b>0F</b>	160 <b>°F</b>	Arbelet elastic hose.
Latex open cell sponge With Peperon fabric on one side	Kennel Shoe Supply Co.	Commercial	150 <b>°F</b>	150 <sup>0</sup> F	Cemented sponge face to sponge face with EC 847 cement or with M4031 cement (King Chemical Co.).

10R 3-24 HOURS - (Continued)	Remorrika	Plexiglass 55, as cast Plexiglass II, as cast Plexiglass No. 2072 Humiscal 1H15	Tenite Butyrate softened at 250°P.	Zipper tubing produced strong offensive odor at 200 <sup>0</sup> F.	Type RFT. Zipper tubing made by Zipper Tubing Co. produced strong odor st 2500F. Specimen melted and adhered to bottom of	gesuccetor. Zipper Tubing No. ZT (Diem.) FI-10-C-0L. Material softened, became tacky.	Nylon LOI	Lexen	Type AL Ensolite comted with U.S. vinyl dip. Vinyl Formal Sponge - Slight vanila odor. Vinyl Formal Sponge cellulose filled. Vinyl zipper tracks produced strong offensive odor at 200°F Tygon No. B-M4-3 vinyl ubing - produced strong odor at	Type N. 1250F. Type SR 24-R256, slightly puncent odor at 1250F. Type SN 24-R256, slightly puncent odor at 1250F.		Fiberglas Reinforced Vinyl (Part No. M.S. 6010).	
6 OXTGEN AT 5 PSIA	Maximum temperature for non-toxic properties	2500 <b>F</b> 2500 <b>F</b> 2120 <b>F</b>	250 <b>0F</b>	160 <sup>0</sup> F 80 <sup>0</sup> F*	250 <b>0F</b> 80 <b>0F</b> :	250 <b>0F</b>	250 <b>0F</b> 160 <b>0F</b>	40091	2000 <b>F</b> 1600 <b>F</b> 800 <b>F</b> # 80 <b>0</b> F	888 888	250 <mark>07</mark>	160 <sup>0</sup> F	1600F
LLIC MATERIALS IN 100	Maximum temperature   for unobjectionsble   odor	250 <b>0F</b> 250 <b>0F</b> 2120 <b>F</b>	250 <b>0F</b>	160 <b>0F</b> 80 <b>0F*</b>	250 <b>0F</b> 800 <b>F</b>	250 <b>07</b>	2500F 1600F	160 <sup>0</sup> F	200 <b>°F</b> 160 <b>°F</b> 160°F 150°F	80.0 9.00 9.00 9.00 9.00 9.00 9.00 9.00	250 <b>%</b>	160 <sup>0</sup> F	160°F
PROPERTIES OF NON-METAL	Specification	MLL-P-8184 MLL-P-6425 Counnercial Connercial	Commercial	MIL-F-3803, Type I	Commercial Commercial	Comercial	Commercial Commercial	Commercial	Commercial Commercial Commercial Commercial	Commercial Commercial Commercial		Comercial	Commercial
OLFACTORY AND NON-FOXIC	Source or Menufacturer	Rohm & Haas Co. Rohm & Haas Co. Rohm & Haas Co. Columbia Tech. Corp.	Eastman Chemical Co.		Raytherm Corp. General Electric Co.	Visking Co.	E.I. Dupont Co.	General Electric Co.	U.S. Rubber Co. Simonize Co. Simonize Co. U.S. Stoneware Co.	U.S. Stoneware Co. DeVilbiss Co. DeVilbiss Co.	3	Minneapolis-Honeywell Co.	<b>3</b> % Co.
	Material	THERMOPLASTICS Acrylic Acrylic Acrylic Acrylic Resin	Cellulose Acetate Butyrate	Polyethylene Polyethylene	Irradiated Polyethylene Irradiated Polyethylene	Irradiated Polyethylene	Nylon Wire with B-22 Nylon Cover- ing	Polycarbouate	Vinyl & Copolymers Vinyl & Copolymers Vinyl & Copolymers Vinyl & Copolymers Vinyl & Copolymers	Vinyl & Copolymers Vinyl & Copolymers Vinyl & Copolymers	Vinyl Electrical Terminals and Knife Splices.	Plestic Insulating Tubing	Ke1-F

POR 3-c4 HVUS - Continued)	Center's 6		SEE NOTS 1 Leflon-fiber		Compound for engraved lettering.	( ast F-ly li נימוד על-'פ מענו <b>ונה (6</b> ט-40) כניפל for 20 דעני, אינע <sup>0</sup> F.	Provuced struck odor. (Astronaut cluch line.) Evoxy liais laulorie (M.S. 0473).	Comst F-141.	Cast F-120.			Fuse El xck Hol (r - ()F-)1 Silicone-filergias Laminate - Ford'r Co)). (Nuiz Weld kpoxy Authreive: Aid tw Rutber; Bastmar 910 adheaive).	Molerate other production into the ectionality.	Material Carkenic from Junt to Gark trown. Increased in thickne s'y ji, slight phenol odor - nat objection ble.	
4 XYGEN AT 5 PSIA	Maxiaum temperature for aon toxic properties		∆ 482°F ∆ 200°F	1,00°F	250°F	<mark>2500 ت</mark> 2	160')F	2- <sub>&gt;</sub> 0 <sup>0</sup> ۴	250 <sup>0</sup> F	160'F	₹.OOF	210 <sup>0</sup> F	-10005	2500 <del>7</del>	20.05
N NE NE NO	Vao lidaa toomijerature for unobjectionucle oo		≜ 482°F (≜ 200°F	180°F	250 <sup>0</sup> F	25005 8005	Teone	250°F	250 F	1600-	3°°°3£	5002	200 <sup>0</sup> F	250 <sup>0</sup> F	دمن <sup>0</sup> ۴
PROPERTINS OF NUM-METAL	She 1f1 at1 20		Journer 1al	Gummercisl		to the second	上に 一日 東昌人 (		лакет 1н.	and the second sec		Commercial	MIL-F-LJJVI, TJPe GML	ML-P-LOJ, Type Fig	MIL-P-79, Type Phi
OLFACTORY AND N.WTUXIC	้งานrce or Manufacturer		E.i. Mujout Co.	simonize Co.	Robre is Hage Co.	Cheit Manuferturfig C:. Shill Chimi al Co.	Mannespolts-Honeywe 1 70.	Coast Mer. If. Co.	"oast Manuf. Cr.	Alriescarch Mfg.	•	Formica Corp.	•	•	1
	%aterial	THERMOFIA TICS - (Continues)	Tefion Tefion Fiberglass Laminate Copper Clad	Ivalon Sponge	Rhorlex Elnck Filifug Com- pound	TURANSIT PLATT 35 'y-ay - Fiterg.as rbuxy - Fiterglas	Truxy & Fiversias	Fulywater a Fiberglas	itenent: * therales	Pur vis Bronze-Allicone Impregnated	wockrostus Wire-Glass and Astestus (1.1.0.0.e impregnatud	Fuse Elock Holder (SCD 45-7.727.)	Melazine & Fiberglas	Phenoit: & Cotton	Phenolic & Paper

1 Regardless of the maximum temperature anticipated for use, the reasons and specific usege of Tefon or Tefon containing products shall be submitted to McDonnell for further submittal to MSA for approval before calling out the material on a design drawing and using the material in an assembly.
Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	утыр
THERMOSET PLASTIC - (Continue	ed)				
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	160%	160°P	Lockform C-605.
Urethane Foem (Rigid)	Emerson & Cusing Inc.	Comercial	80°7**	80°P#	Ecco Foam FP with 12-6 Catalwat (Imsatisfactory at 2500r)
Urethane Foam (Rigid)	Pittsburg Plate Glass Co.	Commercial	1600F	1600F	Selectro Poem 6002-6003.
Urethane Foem (Rigid)	Witco Chem. Co.	Commercial	250 <b>°F</b>	250 <b>0F</b>	Witco Fourez P400, P420 foam.
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	160%	160%	EX100 Nopco Lockfoam.
Uretnane roam (Nigid)	Nopco Chem. Co.	Commercial	1600F	16007	Lockfoem G502 (cured 2 hours @ 180 <sup>0</sup> F)
(DIBTY) SHOJ STRIMAIN	Nopco circa. co.	Commercial	160-7	140-F	Lockfoem E302 with water added (Density 1.5 lbs/cu. ft.,
Urethane Foem (Rigid)	Nopco Chem. Co.	Commercial	350 <b>0F</b>	250 <b>0F</b>	curred 1/2 nour g Lou-F/. Lockfoem A206.
Epoxy Foem (Rigid)	Bakelite Co.	Commercial	160°P	160 <sup>0</sup> F	Bakelite Thermosetting Booxy Resin Foam.
					(M.S. 6293C) Slight odor produced.
<b>Epoxy -</b> Polysmide	Shell - General Mills	Commercial	250 <b>0F</b>	250 <b>0F</b>	P.S. 14030, Compound III (Epon 828 and Versamid 125-70 nerts - 30 nerts) with Monry bulloons (Exercise)
					50 parts: Cure I hr & 200°F.
Epoxy		Commercial	250 <b>0F</b>	250 <b>0F</b>	Bisonite K-1 with K-4 Accel. (Epoxide Battery Case Mat.)
rpoxy	Houghton Lab. Inc.	Comercial	25007	2500F	Hysol 6040, C-1 Hardner, 156 Filler.
EDOLY	Further fiste the Corn.	Commercial	2000	25007	Epoceast 10F.
Eporty		-	28		Epoxylite No. OL. P.S. 11/132 Time 1 Forde Commund Crime 1 Fr. @ 2000
Epoxy	Electronic Production	Comercial	80 <b>0</b>	80°F	Broad No. TC-459. Strong odor produced at 160%
Boncy	and Development Co.	,	1 600	-0-2	
Constant of the second s			J-DOT	1-00T	P.S. 14043 Spoxy - DIA and Glass Flock. (Plastic corner
Epoxy	Minnespolis-Honeywell Co.	Commercial	160°F	160 <sup>0</sup> F	OL MEGICOMBUIC COUCH COTHET). Thermosetting Epoxy Resin (M.S. 6020M).
And to		TETATOMOO	1-002	2002	Styraat No. 2051 epoxy casting resin.
Polyester	1		160 <sup>0</sup> 7	160 <sup>0</sup> F	Laminate per P.S. 14031, Compound VI
Mylar-Paper Laminated Map	St. Louis Mapping Co.	Commercial	140°F	180 <b>°F</b>	Map with Map Colors.
Myler and Quinterre	AfResearch Mfg.	Commercial	300%	3000	
Mylar Costed White	•	Commercial	80°F	80 <b>°F</b>	N. W-138-R-2 (produced offensive odor at 160°F)
Mylar Coated Card Stock	•	F	16007	160%	Wrlar coated rand stocke3 nlv Strathmore

	OLFACTORY AND NON-TOXIC	PROPERTIES OF NON-META	OCT NI STRIFFIC NI JOIN	OXYGEN AT 5 PSIA	OR 3-24 HOURS - (Continued)
Material	Source or Manufacturer	Specifi stion	Maxinum temperature h for 1.00 jectionalie	Maximum temperature for non-toxic reperties	Remarks
THERMOSET PLASTIC - (Continue	()				
Mylar Film - Matte one side	Keuffel-Esser	Commercial	160 <sup>0</sup> F	1.00F	K&E No. 1u3
Mallyl - Phthalate	Minnespolis-Honeyvell Co.	Conner-1al	160 <sup>0</sup> F	160 <sup>0</sup> F	Connector Insert, Homeyvell Part No. 453863.
Ecco-Pond 56C	Emerson & Cuming Inc.	Commercial	200 <sup>0</sup> F	200°F	Ecco Sond S6C (Thimed 10% by wt. with Toluene)
Engraving Stock	Formica Corp.	MI'-P-78A, T.pe MDP	160 <sup>0</sup> F	16-JOF	Formice Grade Bi-1.
FABRICS, FELT, & WEBBIND Decron Webbing	Phoenix Trimming	105 2'-4'-1' IN	160 <sup>0</sup> F	160 <sup>3</sup> F	Decron harness vebiing.
Nylon Cord	1	•	250 <sup>'3</sup> F	250 <sup>0</sup> F	Untreated nylon tyming tape ("ord).
Cotton Duck	1	CCC-C-41), Type I Hard	180 <sup>0</sup> F	180°F	No. 12 cettua dice.
Cotton Webbing	1	MIL-W-53C, Type II Class 4	180 <sup>-J</sup> F	18.0°F	
Nylon Webbing	ı	MIL-W-4086C, Cond. R	160 <sup>2</sup> t	160 <sup>0</sup> F	Hesin Trueted
Map Sized Cotton Cloth	St. Louis Mapping Co.	Comme rc1el	80°F+	80°F*	Produced hot irealag offer at 250°F.
Yellow & Gray Duct Mat.	Arrowhead Products	Commercial	250 <sup>0, t</sup>	250°F	M.A.C. Fart No. 4 -63051-3 (Max. cure).
Wool Felt	AlResearch Mfg.	Commercial	160 'F	160 <sup>0</sup> F	Wool felt with fungus preventive.
Vinyl Costed Nylon Fabric	Cooley, Inc.	MIL-C+20(36, Type I, Jlass II	160°F	160°F	
Neoprene Costed Nylon Fabric	Ponce Cenves Products Co.	Commercial	160 <sup>-1</sup> F	160°F	16 ounce weight, silver color.
Weoprene Coated Nylon Fabric	E.I. Dupont Co.	Commercial		160 <sup>0</sup> F	Fairprene No. 5753.
Glass (untreated)	ŧ	,	400°F	400°F	
PAPER, CORK, & LEATHER Leather	,	۲	160'F	160°5	Oak graincd, unskived leather.
Paper, Kraft	Kraft Paper Co.	Commercial	160 <sup>0</sup> :	IGO <sup>OF</sup>	Transformer insulation (M.S. 6542 - Minnespolis-Honeyvell).

<u> 08 3-24</u> - (Continued)	Кепецткя	XA-193 & XA-194 Space Capsule Coating. Ajax Modified Silicone Insulating Varnish V61V25.	DC 997 Silicone Varnish. X3-4004 Silicone primer overcoated with space capsule coating.	Epon mix insulating lacquer No. F-174-61A & No. F-174-61B, bared @ 1500P for 1 hour	Detries at yor in the second s	Polyurethane coating No. 798 - Produced strong offensive odor - became soft and tacky at 250°F.		TT-B-119 Varnish (Froduced strong odor at 200°F after 150°F cure for 1 hour.)	On panel	M.S. 6668, Paint Spec. No. 043-122-301.	No. D22R2, Elacs	Part No. 418101, lacquer on nameplate. Part No. 446977, lacquer on syncroverter switch.		
& OXYGEN AT 5 PSIA F	Maximum temperature for non-toxic properties	250 <b>0F</b> 2500F	3000 <b>F</b> 2500 <b>F</b>	250 <b>0F</b>	300 <sup>0</sup> F B0 <sup>6</sup> F 20.95 150.95	80°F+	250 <sup>0</sup> F	80 <b>0r</b> +	200 <sup>0</sup> F 2000F	80 <b>0</b> F	1600F	160 <b>0F</b> 160 <b>0F</b>	200 <sup>0</sup> F	160%
OT II STERIALS IN 100	Maximum temperature for unobjectionable odor	250 <b>0F</b> 250 <b>0F</b>	300 <b>°F</b> 250 <b>°F</b>	250 <b>0F</b>	300% 800% 1800% 1800%	80°F*	250 <b>0</b> F	800p#	200 <sup>0</sup> F 200 <sup>0</sup> F	80°r	160 <b>0F</b>	1600F	200 <sup>0</sup> F	1600
PROPERTIES OF NON-META	Specification	Commercial Commercial	Commercial Commercial	Commercial	Commercial Commercial Commercial Commercial	Commercial	Comercial	Commercial	MEL-L-7178 MEL-S-974	Commercial	Commercial	Commercial Commercial	Commercial	Commercial
OLFACTORY AND NON-TOXIC	Source ar Manufacturer	Andrew Brown Co. Shervin-Williams Paint Co.	Dow Corning Corp.	Dennis Chemical Co.	Sherwin-Williams Paint Co. D.J. Peterso Co. Houghton Lab. Inc.	Coast Pro-Seal Mfg. Co.	General Cement Mfg. Co.			Glidden Co.	Sherwin Williams Co.	Minneapolis-Honeywell Co. Minneapolis-Honeywell Co.	3M Co.	AiResearch Mig.
	Material	PAINTS, FINISHES & COATINOS Silicone(Modified) Silicone(Modified)	Silicone Silicone	Έρακγ	Bpoxy Bpoxy Bpoxy Bpoxy	Urethane Coating	Silver Print Conductive Coating	Phenol Formaldehyde Varnish	Lacquer and Surfacer	Spec. M.S. 6668 White Paint	Silk Screen Paint No., D22B2	Flat Black Lacquer Flat Black Lacquer	EC-1103 Costing	303 Stainless Steel with Tin Flate and Lacquer Finish with Compressed Glass Kovar

<del>OR 3-24</del> - (Continued)	Remarks	G-300 Silicome Grease Shell ETR Grease B Shell ETR Grease H DC-4 Grease	Versilube F-50 Silicone Lubricating Oil.	No 200 Fluid	Fluorolube Grease Type "LG"	Fluorolube "FS" Light Grade Oil	Objectionable Odor at 210 <sup>0</sup> F	Orylube Thread Sealant No. 702	Electrofilm 66C Malykote Everlube Drilube Drifube		Offensive odor at 120°F			Part No. 58723M-02 Lubricated with Everlube 810	Very pungent odor at 160°F	Alumnium nuts, carbo war treated A-206 Components, carbo war treated A-206 Components, carbo war and Dag treated A-206 Components, Dag 223 and No-cride treatment	
K OXYGEN AT 5 PSIA 1	Maximum temperature for non-toxic properties	25009 25009 25009 25009	250 <b>%</b>	160°F	250 <b>07</b>	250 <sup>0</sup> T	80 <b>9</b> 5-	250 <b>0F</b>	<b>25007</b> 2500 <b>7</b> 2500 <b>7</b> 2500 <b>7</b>	80°F	30°F	-200°F	200 <sup>0</sup> F	3000F	80 <b>0</b> F	3000 4000 4000 4000 4000 4000 4000 4000	
LLIC MTERIALS IN 100	Maximum temperature for waobjectionable odor	250 <b>9</b> 250 <b>9</b> 250 <b>9</b> 250 <b>9</b>	250 <b>3</b>	160 <sup>0</sup> F	250 <b>07</b>	2500P	80° <del>;</del> #	250 <b>0F</b>	2500 <b>7</b> 2500 <b>7</b> 25502 25502 25502	80 <b>%</b>	80 <b>°</b> #	200 <sup>°</sup> F	200 <sup>0</sup> F	300 <sup>0</sup> F	80 <sup>0</sup> F	2550 <b>9</b> 4000 <b>9</b> 40004 4004 4004	
PROPERTIES OF NON-METL	Specification	Commercial Commercial Commercial Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial Commercial Commercial Commercial Commercial	Commercial	Commercial	Commercial	Commercial.	Commercial	Commercial	Comercial	
OLFACTORY AND NON-TOXIC	Source or Manufacturer	General Electric Co. Shell Oil Co. Shell Oil Co. Dow Corning Corp.	General Electric Co.	Dow Corning Corp.	Hooker Electrochemical Co.	Hooker Electrochemical Co.	Esso Standard Oil Co.	Drilube Corp.	Electrofilm Corp. Alpha Corp. Pverlube Corp. Drilube Corp. Echmman Plating Co.		Monsanto Chemical Co.	Dow Corning Corp.			Monsanto Chemical Co.		
	Material	LUBRICANNS & FLUIDS Silicone Gresse Silicone Gresse Silicone Gresse Silicone Gresse	Silicone Oil	Silicone Fluid	Fluoro Grease	Fluoro 011	Andok "C"	Oxylube Thread Sealant	Dry Film Lubricent Dry Film Lubricent Dry Film Lubricent Dry Film Lubricent Dry Film Lubricent	Synthetic Base (Diester)	Coolanol #35	Dow Corning #7 Compound	led-Plate #250 Anti Seize Compound	Self Locking Hex Nut	05-139 Heat Transfer Fluid	Jo-Bolt Components & Lubrication Treatments	

FOR 3-24 - (Constaned)	Remarks	A-2.56 Commonents, Dag 2-3 treated A-2.56 Commonents, Dag 2-3 treated A-2.56 Commonents, Everlube and Woxide treated A-205 Commonents, Everlube treated A-205 Commonents, Everlube and Woxide treated Lutriceted vit, Nat. Lube #1 - Unsatisfactory at 300°F Lutriceted vit, Translube - Unsatisfactory at 300°F	Armestrouds C-c with Activator "A" cured Armestrongs A-2 with Activator "E" cure: 1 nour at 200 <sup>0</sup> F EC-1409 Fpoxy - 20-1475 Amine Cure, hest cured Epon 8 - Curit, Acart A" (100 parts to ó parts mix), cure: 1/2, curs at 200°F	Epon $\delta c$ -Verssaid 125 ('')%-30%, cure: 1 hour at ${\scriptstyle {\rm LOO}^{\rm O}F})$ FM 47 Type 'O' linesive	Eccobond #TO C Epoxy Adhesive Cured i hour at 200 <sup>0</sup> F Shell Epon Adhesive No. 6 Eiges R-313 Epcxy Pase Adhesive Ecco and #26 Nory Adhesive (used in Carlton Control Valve Without heet cure and with 1-1/0 hour	cure at 2007. Produced strong odor at 300°F Hardner "A" Bonding Material	Pressure Sensitive Adhesive N271 Freestine Sensitire Adhesive Y-9010
& OXYGER AT 5 PSIA	Maximum temperature for non-toxic properties	40009 40009 8009 8009 8009 8009 8009 800	1600F 1600F 2500F 1600F	2500F	160 <sup>0</sup> 1600 <sup>0</sup> 260 <sup>0</sup> 160 <sup>0</sup> 80 <b>°</b>	160°F 160°F	3000 <sup>0</sup> 5 300
ALLIC MATERIALS IN 100	Max: num tempe: ature for unobjectionsule odo:	9005 9005 9005 9005 9005 9005 9005 9005	160 <sup>, F</sup> 160 <sup>, F</sup> 250 <sup>0</sup> F 260 <sup>5</sup> F	250 <sup>0</sup> F 250 <sup>2</sup> F	186 <sup>0</sup> 7 18607 18609 18609 18609 18809 18808	160 <sup>0</sup> ۴ ا	300°F 300°F
PROPERTIES OF NOL-META	Specification	Commercial	Commercial Commercial Commercial	Commercial Commercial	Commercial Commercial Commercial Commercial Commercial	Commercial Commercial	Commercial Commercial
OLFACTORY AND NON-TOXIC	Source or Manufacturer	ued) Brerlube Corp.	Armstrong Products Co. Armstrong Products Co. 3M Co. Suell Chemical Co.	Shell Cjemical Co. Hloomingdale Rubber Co.	Emerson & Cumlag Lac. Sheil 341 Co. Carl H. Piggs Co. Emerson & Cuming Inc. W. S. Themben & Co.	Carl H. Biggs Co. AiResearch Mfg.	Dov Coraing Corp. 3M Co.
	Material	LUBRICANTS & FLUIDS - (Contin JE.)t Components 2 Tubrication Treatments Everlube 620 Materia	ADHESIVES Epoxy - Amine Epoxy - Amine Epoxy - Amine	Epoxy Poly <del>ami</del> de Vinyl - Phenolic	Epoxy Epoxy Epoxy Epoxy Adhesives - 16540	Bonding Agent R314 Caram 214	Adhesive, Pressure Sensitive Adhesive, Pressure Sensitive

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
CEMENTS Neoprene-Phenolic	3M Co.	Commercial	250 <sup>0</sup> F	250 <sup>0</sup> F	DC-047
Buna N-Phenolic	3M Co.	Commercial	60°F	80 <sup>0</sup> F	BC-776
Neoprene	3H Co.	Commercial	250 <b>0F</b>	250 <b>0F</b>	
Silicone	Dow Corning Corp.	Comercial	250°F	2500F	A-4000 Cement with XY-27 Catalyst
Stabond Cement	American Laytex Cc.	Commercial	€00 <sup>5</sup> **	80°F*	Stabond 3-136 Cement - strong odor produced at 250°F
Kodak Dry Mount Cement	Eastman Chemical Co.	Commercial	160°F	160°F	For leminating Map to Card stock.
SEALANTS (ELASTOWERS) Silicone Primer (Encapsulating)	3M Co.	Commercial	250 <sup>0</sup> F	250 <sup>0</sup> F	EC-1694 Primer for use with EC-1663 Potting Compound
Silicone (Encapsulating) Silicone (Encapsulating)	3M Co.	Commercial Commercial	250 <b>0F</b> 800 <b>F</b>	250 <b>0</b> F 800F*	EC-1663 Potting Compound RTV-502 Silicone Potting Compound (Produced strong musty dong at 2500P)
Silicone (Structural RTV)	General Electric Co.	Commercial	4000t	1400°F	RTV-90 Sealant
Silicome (RTV) Silicome (RTV) Silicome (RTV) Silicome (RTV)	Products Research Co. Dow Corning Corp. Dow Corning Corp.	Commercial Commercial Commercial Commercial	400 <sup>0</sup> F 250 <del>0</del> F 3(J) <b>0</b> F	400 <b>°F</b> 2500F 2500 <b>F</b> 300 <b>0</b> F	PR 1910-6 Silicome RTV Sealant RTV-Q-3-0121 Silicome Sealant RTV-731 Silicome Sealant RTV-501 Silicome Ambert
Urethane	Coast Manufacturing Co.	Commercial	80 <sup>0</sup> F	80°F	Coast Proseal #777 Potting Compound
Oil Resistant Elastomer		Commercial.	160%	160°F	Auti-Taumper Compound BC-1252
Locktite "A"	Perkin-Elmer Corp.	MIL-S-22473 Grade A	253°P	250 <sup>0</sup> F	
Locktite "C"	Perkin-Elmer Corp.	MIL-S-22473 Grade C	2500F	250 <b>0F</b>	
TAPES Silicone & Fiberglas	<b>Fermacel</b> Corporation	Commercial	250°F	2500	P-211 Permacel Tape
Fiberglas with Adhesive Fiberglas with Adhesive	3M Co. Minneapolis-Honeywell Co.	MIL-I-15126	80.2.** 16.00F	80 <sup>3</sup> P# 1600F	No. 27 Objectionsble odor produced at 300°F M.S. 6771

OR <u>3-24</u> - (Continued)	Remarks		Scotch Polyester Tape #5 M.S. 6856, Fressure sensitive - thermosetting	Conclon 506-81 over Narmco Tape 103, Type I film and Narmco Tape 103 Type III and IV (506-506)	I-9050	Scotch #69 Electrical Tape	Type 490 Type 499							#1448 Elack and White Marking Ink VF200 Red Marking Ink 100 Series Green Ink	Amodized Aluminum foil type nameplate. Any dyed, amodize and etched vrinting type nameplate is satisfactory	if all photo emulsion is removed. Metalcals with adhesive backing Metal foil nameplates with heat or solvent activated	auresive. Metal foil identification plates with EC-583 adhesive (3M CO.) Heat or Solvent applied.	V. yl Cals. FEE CEE 1001 Mylar Pressure Sensitive Label.	
6 OXYGEN AT 5 PSIA F	Maximum temperature for non-toxic properties		2500F 1600F	250 <b>°F</b>	250 <sup>0</sup> F	250 <b>0</b> F	160°F 160°F	<b> </b>						250 <sup>0</sup> F 200 <b>9</b> F 1600	250 <sup>0</sup> F	160 <sup>0</sup> F 250 <sup>0</sup> F	160 <sup>0</sup> F	160 <sup>0</sup> F 200 <sup>0</sup> F	
LC MATERIALS IN 100	eximum temperature h or unobjectionable i dor		2500F 1600F	250 <sup>0</sup> F	250 <sup>0</sup> F	250 <sup>0</sup> F	160 <b>0F</b> 160 <b>0</b> F							250 <b>0F</b> 2000F 160 <sup>3</sup> F	250 <sup>0</sup> F	160 <sup>0</sup> F 250 <sup>0</sup> F	160 <sup>0</sup> F	- 50 <sup>0</sup> F 200 <sup>0</sup> F	
PROFERTIES OF NON-METALL	Specification f		Commercial Commercial	Commercial	Commercial	Commercial	Commercial Commercial	lbove	lbove	Dve	lbove	Development Department	Above	Commercial Commercial Commercial	Commercial	Commercial Commercial	Commercial	Commercial Commercial	
OLFACTORY AND NON-TOXIC I	Source or Manufacturer		3M Co. Minnespolis-Honeywell Co.		3M Co.	3M Co.	3M Co. 3M Co.	See Rubber Materials Section /	See Rubber Materials Section /	See Cork Materials Section Ab	See Rubber Materials Section /	Consult Meterials and Process	See Plastic Materials Section	Banner Rubber Stamp Co. Organic Products Co. Organic Products Co.	Nelson Nameplate Co.	Alfesearch Mfg. Alfesearch Mfg.	AlResearch Mfg.	AiResearch Mfg. FEE-CEE Tape & Lable Co.	
	Material	TAPES - (Continued)	Polyester Polyester	Thermal Sensing Element Patch	Heat Reflective	Electrical Tape	Magnetic Tape Magnetic Tape	GASKETS & PACKINGS Asbestos-Rubber	Asbestos-Rubber Graphite	Cork-Rubber	Rubber	Asbestos and Binder	Plastic	INKS & NAMEPIATES Ink Ink Ink	Nameplate (Metal)	Nameplate (Metal) Nameplate (Metal)	Nameplate (Metal)	l'ameplate (plastic) Nameplate (plastic)	

	OLFACTORY AND NON-TOXIC	PROPERTIES OF NON-MET	ALLIC MATERIALS IN 100	& OXYGEN AT 5 PSIA 1	<u>08. 3-24</u> - (Continued)
Material	Source or Manufacturer	Specification	Maxinum temperature for unobjectionable oder	Maximum temperature for non-toxic properties	Remarks
MISCELLANEOUS CONPONENTS	Johns Manville Co.	Commercial	200 <sup>0</sup> F	200 <sup>0</sup> F	
No XR-5005 Scotchcast Resin, 55-9-100 Chrysler Cycle Weld, M-19 Lamination	AlResearch Mfg.	Comercial	300 <sup>0</sup> F	300 <sup>0</sup> F	
"HO" Varglass-Fiberglass Eraid with light treatment of Resin	AiResearch Mfg.	Commercial	lóo <sup>o</sup> f	lóor	
F141 Prepreg - AF106 Adhesive Aluminum Core Honeycomb		Connercial.	انىمە	160°F	
Aluminum Face-Aluminum Core Honeycomb Structure Bonded With FN47 Adhesive		Commercial	250 <sup>0</sup> F	. 50°a	
Bl Glass Insulator	AiRescarch Mfg.	Commercial	160 <sup>0</sup> F	1 ,0 <sup>0</sup> F	
Warning Lite Assembly	Grimes Mig. Co.	Commercial		4°(- 5	M.A.C. Part No. 42-7220-37 & 45-73720-117
Mallory Mercury Battery	Mallory	Commercial	5 Q 2	20 <b>J</b> F	
Rotary Potentiometer		Courner c 1al	160°:	1:004	M.A.C. Part No. 4 - 04717-5
Astronaut Pencil	C.H. Swan Co.	Commercial	Iénci	160 <sup>9</sup> F	Astr maut Fracil , tabilo 2005 - All
Capacitor, Paper Type	Grimes Mfg. Co.	Commercial	250°F	25001	Cornell Dubilier Nr. Phér33
Microsvi tch	AiResearch Corp. Hayden Mica Co., Inc.	Corrate 161	160°F	16: <sup>2</sup> F	Pert 10. 5.4-501-1003 Pert 10. 61.5%
Grade 45, Silica Gel	Davidson Chemical Cor.	Commerc, al	250 <sup>3ج</sup>	40.042	
Microdot 50-3804 Cable	Microdot Inc.	Commercial	200 <b>0F</b>	Ac 0. 2	
Somp Base Crayoff Crayons	Crayoff Corporation	Commercial	250 <sup>0</sup> F	2.00 <sup>2</sup> F	Applied, then woshed off with cold tap water and wiped dry.

	TTYOT-NON MAN INGA-LOYI	LAUFERTLES UP NON-MELL	MT UT GTVTUSTUU ATTT		
Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
MISCELLANEOUS COMPONENTS - (Continued)					
Nafil Resin Foam		Commercial.	160°F	160 <sup>0</sup> F	Cured at 160°F for 2 hours at 5 PSI
Nafil Resin Foam with Dennis Epoxy	Dennis Chemical Co.	Commercial	160 <sup>0</sup> F	160 <sup>0</sup> F	Cured at 160°F for 2 hours at 5 FSI
Electrical Hook-up Wire	Beldon Mfg. Co.	MIL-W-16878 Type B	2000	200 <i>0</i> F	No. 8503
Printed Circuit Board	Taylor Fibre Corp.	Commercial	200 <sup>0</sup> F	200 <i>0</i> F	No. GEC-500
AN Muts with Vulcanized Fiber Inserts (Elastic Stop Muts)		Commercial.	250 <b>0</b> °	250 <b>0F</b>	
Microphone Assy		Commercial	1600F	1600F	M.A.C. Part No. 45-65035-1
Wire, RG 58/U	Plastoid Corp.	Commercial	800F#	80 <b>0F</b> *	Siightly objectionsbie and mildly pungent odor at 200 <sup>0</sup> F
Wire, 20GA	Brand Rex Cable Corp.	Commercial	80 <mark>07**</mark>	30 <sup>0</sup> 5**	Slightly objectionsble and mildly pungent odor at 200°F
Connector Connector	Cannon Viking	Commercial Commercial	80.0 <mark>5.</mark> **	80 <sup>0</sup> F* 80 <sup>0</sup> F*	Slightly objectionable and mildly pungent odor at 200°F Slightly objectionable and mildly pungent odor at 200°F
Terminal Block	Jones	Commercial	80°F*	80 <sup>0</sup> F*	Silightly objectionsble and mildly pungent odor at 200 <sup>0</sup> F
Circuit Breeker	Heinemann Electric Co.	Commercial	250°F	250 <b>°F</b>	No. 6250

Mg FLIGHT Trace Trace Trace Trace Ч MA-8 Trace 5.3 8.7 **4**•9 0.6 15.6 ł 1 ENCLOSURE 1 - Concentrations given are approximate and represent the parts per million and the actual weight in milligrams that would be in the 60 cubic foot cabin V FLIGHT MA-8 PPM Trace Trace 0.302 Trace Trace Trace 2.88 3.81 2.03 7.16 • 1 MA-7 Mg FLIGHT Data from N. Irving Sax, Dangerous Properties of Industrial Materials 0.17 1.6 2.7 47.1 4.6 1.8 1.9 e.0 8.9 ł ł CONTAMINANTS RECOVERED FROM CAPSULE ATMOSPHERE OF MERCURY FLIGHTS 1 1 t 0.156 MA-7 PPM FLIGHT 0.896 0.585 0.151 1.18 1.46 4.09 2.11 25.5 1 1 1 . Mg FLIGHT MA-6 0.49 0.17 0.43 20.2 16.3 8.7 **4.**0 2•3 1.8 7.2 2.1 1.3 FLIGHT **MA-6** 0.865 0.156 0.151 0.603 0.568 0.597 MHA 8.83 5.89 1.16 1.15 1 1 **6.**8 Mg SCRUBBED Trace **MA-6** Trace Trace Trace 50.0 <del>с</del>. К 56.0 t 1 I ł ı 4 1 SCRUBBED MA-6 PPM Trace Trace Trace 1.44 Trace 27.1 25.7 1 1 I ŧ I 1 Preliminary Information. ł 1 1 area at 25°C. DN AIR MAC <u></u> 80 80 20 8 35 28 8 8 g 1000 1000 g 1 Æ Trichlorofluoromethane Vinylidene Chloride Methylene Chloride Methyl Chloroform CONTAMINANT General Vinyl Chloride Methyl Alcohol Ethyl Alcohol Unidentified Cyclohexane ব N) P-Dioxane Benzene Toluene NOTES:

	MA-8 Mg WT.Tream		850	0251
tinued)	MA-8 2 PPM TLIGHT		262	1320
<u>urs</u> (cont	MA-7 Mg LIGHT F		7500	1300
RY FLIG	MA-7 PPM LIGHT F		5310	0880
OF MERCU	MA-6 Mg LIGHT F		1490	3240 1
OSPHERE	MA-6 PPM LIGHT	-	151	OZT
SULE ATM	A-6 Mg JBBED F	e		3.
KOM CAP	ED SCRU	Trac	1510	370
	MA-6 PPM SCRUBBI	Trace	4650	3560
	(1) MAC PPM TN AIR	2	1000	5000
	Et			
	ONTAM INAN	ehyde	н	Dioxide
	Ö	Formald	Freon I	Carbon ]

#### APPENDIX C

# DYNASOAR SPACE CABIN MATERIALS LIST

The source of this data is The Boeing Corporation. The list is approximately 30% complete.

#### I. Plastics

- A. Thermoplastic Materials
  - 1. Acrylic
    - a. MIL-P-5425
    - b. MIL-P-8184
    - c. MIL-P-8257
  - 2. Cellulose acetate (MIL-O-8587)
  - 3. Cellulose Butyrate (MIL-P-3414)
  - 4. Kel-F (Polychlorotrifluoroethylene AMS 3650A)
  - 5. Nylon (MIL-P-17091)
  - 6. Polyethylene (MIL-P-3083)
  - 7. Polypropylene
  - 8. Polystyrene
    - a. Rexolite cross linked styrene (MIL-P-3827A)
    - b. Styrene Rubber Copolymers (BMS-8-35)
    - c. Thermoplastic Polystyrene
  - 9. Polyvinyl Chloride (MIL-P-3410)
  - 10. Polyvinylidene Chloride (MIL-P-3411)
  - 11. Polyvinyl Butyral (MIL-G-8602)
  - 12. Teflon 100X Polytetrafluoropropylene
  - 13. Teflon Polytetrafluoroethylene (AMS 3651)
- B. Thermosetting Materials
  - 1. Polyester
    - a. Common Polyesters Resin (MIL-R-7575A)
    - b. Tri-Allyl-Cyanate (TAC) Resin (MIL-R-25042)
  - 2. Epoxy Resin (MIL-R-9300)
  - 3. Phenolic Resin (MIL-R-9299)
  - 4. Silicone Resin (MIL-R-25506)
  - 5. Phenyl Silane (MIL-R-9299)
  - 6. Alkyd Resins (MIL-M-14E)
  - 7. Melamine (MIL-P-15037)

These listed specifications are for Reference only.

#### II. Elastomers

- A. Acrylonitrile
- B. Natural
- C. Silicone (G. E. -RTV-60)
- D. Neoprene Polymers of Chloroprene

- E. Butyl Isobutene and isoprene or butadiene
- 2234 F. Polyurethane - diisocyanate and glycol - adipic acid esters
- G. Hypalon chlorosulfonated polyethylene

#### III. Lubricants

- A. Solid Film Dry Lubricants BMS –3–3
- B. Greases
  - 1. Petroleum oil thickened with Sodium, Calcium or Lithium Soaps.

\*\* ± ± ±

- MIL-G-3545 Lubricating Grease, High Temperature a.
- b. MIL-G-7711 Lubricating Grease, General Purpose
- MIL-G-7187 Grease, Graphite, Aircraft Lubricating c.

Synthetic oil thickened with various thickeners 2.

- MIL-G-7118 Grease, Aircraft Gear & Actuator Screw, Diester a. type oil, Lithium Soap Thickener
- b. MIL-G-7421, Grease, Extreme Low Temperature Diester Type oil, Lithium Soap Thickener
- c. MIL-G-25013 Ball & Roller Grease, Extreme High Temperature, Silicone Fluid, thickened with indanthrene type thickener.
- d. MIL-G-25760 Ball & Roller Grease, Wide Temperature Range, Pentaerythritol ester fluid, aryl urea thickener or other ester type with indanthrene type thickener
- 3. Radiation Resistant Grease
- C. Fluids
  - 1. Petroleum Oil MIL-L-7870 Lubricating Oil, Low Temperature
  - 2. Synthetic Diester type MIL-L-6058 Lubricating Oil Aircraft Instrument 3. Synthetic Silicone Type

[1] A. S. S. Martin, M. S. Martin, and T. Martin, Phys. Rev. Lett. 19, 121 (1997).

- - a. General Electric Versilube F-50
  - b. Dow Corning F-60

#### IV. Sealants

- A. BAC 5010
  - 1. Type 2
    - a. Monsanto RF 2905
    - b. Catalin 726

- c. Casophen RS-216
- d. Bostik 1007
- 2. Type 5
  - a. Bostik 1008
- 3. Type 12 (BMS-5-55)
  - a. Minnesota Mining & Mfg. EC-1128
- 4. Type 30 (BMS-5-43)

a. Dupont 5458

- 5. Type 34 (BMS-5-56)
  - a. Minnesota Mining & Mfg. EC 873
- 6. Type 38 (BMS-5-29)
  - a. Minnesota Mining & Mfg. EC-776R
  - b. Epon 828
  - c. Epon 812
  - d. Versamid 115
  - e. Versamid 125
  - f. Hysol 2022
  - g. SaCo 2862, Comp. I
  - h. Hysol AK-7
  - i. SaCo 2862, Comp. II
  - j. Cement Epoxy Polyamide

7. Type 40 (BMS-5-14)

- a. Pro-Seal 590 M
- b. U.S. Rubber M-6249
- 8. Type 42 (BMS-514)
  - a. Dow Corning Silastic Adhesive S-2200
  - b. Dow Corning A4094 Primer
- 9. Type 44 (BMS-519)
  - a. PR-9021-A-1
  - b. PR-9021-A-2
  - c. PR-9021-A-4
  - d. PR-9021-B-1
  - e. PR-9021-B-2
  - f. Pro-seal 719-A-2

- g. Pro-seal 719-B-2
- h. 3202-B-1
- i. CS-3293-B-2

10. Type 45 (BMS-5-58)

a. Dow Corning RTV-Silastic 501 (Catalyst A)

b. Dow Corning A-4094 Primer

11. Type 46

- a. Dow Corning A-4000 Silicone Adhesive
- b. Dow Corning A-4014 Primer
- c. Dow Corning A-4000 Catalyst

12. Type 47

a. Mystic A-117, Silicone

b. Corning C-269, Silicone Adhesive

13. Type 48 (BMS-5-30)

- a. Bostik 4040
- b. Minnesota Mining & Mfg. EC1458

14. Type 49 (BMS-5-34)

a. Churchhill 3C-90 '

15. Type 50 (EMS-5-36)

a. Eastman 910

16. Type 51

a. Pro-Seal 501

17. Type 53

- a. Gaco-N-29 Adhesive
- b. Gaco-N-39 Accelerator
- c. Gaco-N-15 primer

18. Type 54 (BMS-5-25)

a. Epon 901 & Catalyst B-1

- b. Epon 901 & Catalyst B-2
- c. Epon 901 & Catalyst B-3

19. Type 55

a. Thixon IB

- B. BMS-5-17, HT-424
- C. BMS-5-20, Harmtape 102, Types 1 and 2
- D. BMS-5-15, AF-30/EC-1593

#### V. Adhesives

- A. BMS-5-33 (Pressure Sealing RTV Silicones)
  - 1. Dow Corning 3-0014
  - 2. General Electric RTV-90
  - 3. Products Research PR-1910
  - 4. Coast Pro-Seal 792
  - 5. Minnesota Mining & Mfg. Co. 1667

#### VL Interior Finishes

- A. Alkyd
  - 1. MIL-P-6889A primer
  - 2. MIL-P-8585 primer
  - 3. TT-E-489 enamel
  - 4. TT-E-527
- B. Vinyl Chloride Polymers
  - 1. MIL-P-15930 primer
  - 2. MIL-E-15935 enamel
- C. Vinyl Acetal
  - 1. MIL-G-8514 wash primer
  - 2. MIL-T-15328 wash primer
- D. Catalyzed Epoxy
  - 1. BMS-10-11 Type 1 primer
  - 2. BMS-10-11 Type 2 topcoat
- E. Silicones
  - 1. Dow Corning 805, resin
  - 2. Dow Corning 806, resin
  - 3. Dow Corning 807, resin

F. Chlorinated Materials

- 1. Chlorinated Rubber (Parlon)
- 2. Chlorowax 70
- 3. Arochlor 1254
- G. Polyurethanes
  - 1. Mobay Co. Mondur CB-75 with Multron Resins

# H. Nitrocellulose and Lacquers

- 1. MIL-L-7178
- 2. MIL-L-6805
- I. Acrylic
  - 1. Sherwin Williams M49YC10 enamel

## APPENDIX D

# THERMAL DECOMPOSITION AND TOXICITY DATA

FOR SELECTED ORGANIC MATERIALS

The Boeing Company, in 1959, initiated a program to study the thermal degradation of certain selected materials which might be employed in space cabins. This study is reported in Boeing Company DocumentNo. D2 90202, portions of which are discussed herein. The laboratory studies included thermogravimetric analysis of individual materials, chemical identification of breakdown products, and relative indication of acute animal toxicity. These tests were conducted at reduced pressure under conditions simulating hypothetical space cabin environments.

A Stanton automatic recording thermogravimetric balance was used to determine the characteristic temperature profiles of the materials under study. To simulate a reduced pressure environment, the thermogravimetric balance was operated in an altitude chamber at 18,000 ft. (7.35 psia). Chemical analyses were made by gas chromatography and mass spectrometry. A Kitagawa Toxic Gas Analyzer was used for lowlevel carbon monoxide determinations. Several groups of materials, primarily elastomers and plastics were selected for the initial evaluation program. The decomposition temperatures, ranges, and other data from the thermogravimetric analyses are shown in Table 23.

The initial weight loss is the lowest temperature at which weight loss was recorded. These losses are usually due to loss of residual solvent or absorbed water but in some instances may be caused by very slight degradation.

The empirical decomposition temperature is arbitrarily taken as the lowest temperature at which a line drawn  $60^{\circ}$  to the horizontal axis is tangent to the weight loss curve. This is an empirical method of picking a temperature at which definite sample degradation occurs that can be readily duplicated by any operator. Some materials held at this temperature will degrade completely while others degrade only partially. Curve inspection will usually indicate the thermal behavior to be expected.

The maximum rate decomposition temperature is taken at the inflexion of the weight loss curve and represents the point of most rapid degradation of the material.

Range of accelerated rate change is the temperature range in which the thermogram depicts a steeper slope than either the preceding or subsequent slope. First and second merely indicates the order of occurrence in the direction of increasing temperature. This phenomenon of slope increase indicates the start of acceleration of a reaction, while slope decrease indicates the finish or deceleration of the previous reaction.

Final weight loss is the temperature range in which final decomposition is completed. In most polymers, a carbonaceous residue is formed which will gradually burn off, leaving an ash if nonvolatile inorganics are present.

Chemical analyses were made of three of the samples with aid of mass spectrographic and gas chromatographic techniques. The result of these analyses are shown in Table 24.

To determine the relative acute toxicities of the different materials, a large bell jar apparatus was modified to serve as an animal chamber. Inside the bell jar was a small furnace for material decomposition, a fan for circulation and a wire-net TABLE 23

TGA DECOMPOSITION TEMPERATURE, <sup>OF</sup>, 1/2 ATWOSPHERE PRESSURE

П	Initial Woist	Empirical	Maximum	Range of	Accelerated	
Sample Name	Loss	tion Temp.	vecomposi- tion	Rirst	e Change Second	Final Weight Loss
Acrylonitrile Alkvl Resin	390	630	800-850	002,-089	750-1000	1000-1400
Laminate Cellulose Acetate Cellulose Acetate	260 350	610 640	650 <b>-</b> 700 700-750	610-800 640-780	900-1000 1000-1300	1000-1250
Epon 828 Laminate *Kel-F 240	330 400 740	040 610	700-750 650-700 750-800	640-850 610-700 710-850	1000-1230 900-1100	
Melamine Methvl Methacrvlate		010	700-750	610-800 610-800	1300-1400	
Nylon FM2 Phenolic Besin	000 000 000 000 000 000 000 000 000 00	820	000-010 000-010 000-010	820-1100		1100-1300
Polyester Resin	1 2	2	000000	DOOT-OC /		0041-0041
Laminate Dolwathulono	340 010	640	700-750	640-800		900-1050
Polypropylene	004	030 610	700-750	830-970 610-820	1   1   1   1   1   1   1   1	1 1 6 1 8 1 8 1
Polystyrene	430	650	700-800	650-800		800-950
rolyvinyl Butyral Polyvinyl Chloride	170 480	720 600	800-850 650-750	720 <b>-</b> 950 600-850	1100-1250 900-1400	
Silicone DC 916 Silicone Resin	260	850	950-10 <b>50</b>	850-1100		1100-1350
DC 7141 Laminate	200	0770	1000-1100	770-1280		
*Terion Butyl 325 (Gum Stock)	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	910 620	1000-1050 670-720	910-1100 620-760		760_000
Hypalon 20 Natural Gum Rubber	340	550	870-920	550-750	800-950	950-1100
(Smoked Sheet) Neoprene WRT (Gum	390	640	700-750	640-0	8 1 1 1	800-1130
Stock) Polvurethane Adimene	360	550	600-650	550-700	750-950	0071-056
C	390	540	750-800	540-900	1100-1300	

\*Teflon and Kel-F decomposed into materials that attacked the container and rendered accurate interpretation of the last portion of the analysis infeasible. However, if either material were heated at any temperature in the "Range of Maximum Decompo-sition", major degradation would be achieved.

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# TABLE 24

# CHEMICAL ANALYSIS OF THERMAL DEGRADATION PRODUCTS

Material	Products Detected By Mass Spectrograph	Products Detected By Gas Chromatograph
Butyl Rubber	Carbon Dioxide Carbon Monoxide Ethane Propane	Carbon Dioxide Carbon Monoxide
Acrylonitrile	Carbon Dioxide Carbon Monoxide Ethane	Carbon Dioxide Carbon Monoxide Ethane Hydrogen
Neoprene	нсі	Carbon Dioxide

# TABLE 25

## RELATIVE TOXICITY

Substance	LD <sub>50</sub> (mg/liter*)
Elastomers: Acrylonitrile Butyl Rubber 325, Gum Stock Hypalon Natural Gum Rubber, Smoked Sheet Neoprene WRT, Gum Stock Polyurethane Adiprene C Silicone Rubber, DC 916	19 38 66 11 10 8 4
Plastics:	3 52 7 80 26 17

\* Milligrams of material decomposed.

cage to house four mice. Accessory equipment included a pressure manometer, a Variac for furnace control, a paramagnetic oxygen gas analyzer, and a Hempel carbon dioxide analysis unit. A cold water cooling coil removed heat from the furnace wall preventing a temperature build-up within the chamber.

For toxicity determinations, a small weighed sample of material was placed in the furnace crucible, four mice were placed in the cage, and 10 grams of dessicant was spread out in a flat metal receptacle for humidity control. The apparatus was evacuated to 25,000 ft. and pure oxygen leaked in to bring the altitude down to 18,000 ft. This resulted in a partial pressure of 156 mm for oxygen, equivalent to sea level. Tests made with control animals indicated no pathological effects due to the altitude changes. A comparison of the relative toxicity of several materials is shown in Table 25. Since only four animals were used per trial, the statistical significance of the data is limited.

## APPENDIX E

# POLYMER IDENTIFICATION

Some of the polymers, such as Teflon, are homopolymers and, therefore, easily identifiable by specific chemical formulas. Others, such as epoxies or polyesters, are copolymers with other monomers or polymers thus making only generic chemical formula identification possible. Since most commercial polymers are either copolymers, or complex mixtures of copolymers, with solvents, plasticizers and fillers added to obtain the desired physical and chemical properties, their complete chemical formula identification cannot be made without direct information from the respective manufacturers.

1. Acrylics

Homopolymers of such acrylates as acrylic acid,  $CH_2 = CHOOH$ , methyl acrylate,  $CH_2 = CHCOOCH_3$ , methyl methacrylate,  $CH_2 = CCOOCH_3$ , ethyl acrylate,  $CH_2 = CHCOOC_2H_5$ , and acrylonitrile,  $CH_2 = CH-CN$ , or copolymers with other monomers, the most important of which are: vinyl chloride, vinyl acetate, vinylidene chloride, vinylpyridine, butadiene and styrene. Typical cast acrylic is methacrylate "Plexiglas" of Rohm & Haas, typical acrylic rubber is a copolymer of acrylonitrile with butadiene (and styrene) such as "Hycar" of Goodrich, or Goodyear's "Chemigum."

2. Alkyd Resins

Oil, modified polyesters (vide 13).

3. Cellulose Acetate

An ester of cellulose, obtained from natural sources such as cotton linters or chemical pulp, and acetic acid,  $CH_3COOH$ .

4. Cellulose Butyrate

Mixed ester of cellulose and acetic-butyric anhydrides.

5. Dacron (DuPont)

Poly (ethylene terephthalate) polyester fiber.

~ 
$$\circ$$
 (CH<sub>2</sub>)<sub>2</sub>  $\circ_2$ C -  $\bigcirc$  --Co<sub>2</sub> (CH<sub>2</sub>)<sub>2</sub>  $\circ_2$  C--  $\bigcirc$  --Co<sub>2</sub> ~

#### 6. Epoxy Resins

Resins which are derived from the epoxide group are  $CH \rightarrow CH_2$ . A typical example of an epoxy resin is the product of reaction between bisphenol A and epichlorohydrin.

HO - 
$$\bigcirc - \stackrel{\circ}{C} - \stackrel{\circ}{C} - \stackrel{\circ}{C} - \stackrel{\circ}{O} - OH + H_2C \xrightarrow{\circ} CHCH_2CI \xrightarrow{\circ}$$

$$H_{2} \stackrel{C}{\smile} - \stackrel{CHCH}{\frown}_{2} - \left[ \begin{array}{c} 0 - \stackrel{CH}{\bigcirc} - \stackrel{1}{\bigcirc} - \stackrel{C}{\bigcirc} - \stackrel{O}{\bigcirc} - \stackrel{OCH}{\bigcirc}_{2} \stackrel{CHCH}{\longleftarrow}_{2} \\ \stackrel{C}{\leftarrow} \stackrel{1}{\underset{3}{}} \\ - 0 - \stackrel{O}{\bigcirc} - \stackrel{CH}{\underset{1}{}}_{3} \stackrel{C}{\bigcirc} - 0 - \stackrel{CH}{\underset{2}{}} \stackrel{CH}{\underset{1}{}}_{0} \\ - 0 - \stackrel{CH}{\bigcirc} - \stackrel{C}{\underset{1}{}}_{0} \stackrel{C}{\leftarrow} - \stackrel{C}{\underset{1}{}}_{0} - 0 - \stackrel{CH}{\underset{2}{}} \stackrel{CH}{\underset{1}{}}_{0} \\ + \stackrel{HC}{\underset{1}{}}_{0} + \stackrel{C}{\underset{1}{}}_{0} + \stackrel{C}{\underset{1$$

7. Kel-F

A polymer of chlorotrifluoroethylene, whose molecular structure is:

$$\begin{array}{ccccc} F & C1 & F & C1 \\ \thicksim & C & - & C & - & C & - & C \\ F & F & F & F & F \end{array}$$

8. Melamine Polymers;

Polymers of melamine,



such as formaldehyde, CH<sub>2</sub>O

9. Mylar (DuPont)

Poly (ethylene terephthalate) extruded film of the same chemical composition as Dacron.

10. Nylon

Any of the long chain polyamide polymers such as "nylon 66"

 $\sim$  CO (CH<sub>2</sub>)<sub>4</sub> CONH (CH<sub>2</sub>)<sub>6</sub> NH  $\sim$ 

11. Orlon (DuPont)

An orientable fiber made from polymers containing mostly acrylonitrile,  $CH_2 = CH - CN$ , in the chain.

12. Phenolic Polymers

Products of reaction between phenol,  $\bigcirc$  - OH and an aldehyde such as formaldehyde, CH<sub>2</sub>O. The polymers are usually tridimensionally cross-linked.

#### 13. Polyesters.

Unsaturated polyesters of such acids as maleic anhydride,

$$O = C \underbrace{CH = CH}_{O} = O, \text{ fumaric acid, HOOCCH} = CHCOOH$$

and polyhydroxyl alcohols such as ethylene glycol,  $HOCH_2 CH_2OH$ , and propylene glycols,  $HOC_3H_6OH$ , cross-linked to thermosetting copolymers with vinyl monomers, usually styrene.

#### 14. Polyethylene

A polymer formed from ethylene

$$CH_2 = CH_2 \xrightarrow{H} C - C_{H} \xrightarrow{H} H$$

15. Polypropylene

A polymer formed from propylene.

(a) atactic form (Random)

$$CH_3 CH = CH_2 \xrightarrow{H} CC_{H_3} CH_2 - CH_2 - CH_2 - CH_3 CH \sim$$

(b) syndiotactic form (stereospecific)

$$\begin{array}{c} \mathrm{H} \\ \mathrm{C} \\ \mathrm{C} \\ \mathrm{CH}_{3} \end{array} - \begin{array}{c} \mathrm{CH}_{2} \\ \mathrm{CH}_{2} \end{array} - \begin{array}{c} \mathrm{CH}_{3} \\ \mathrm{CH}_{2} \end{array} - \begin{array}{c} \mathrm{CH}_{2} \\ \mathrm{H} \end{array}$$

16. Polystyrene

A polymer of styrene

$$\bigcirc - CH = CH_2 \xrightarrow{\sim} CH - CH_2 \xrightarrow{\sim} \bigcirc$$

(a) Rexolite - Cross linked Styrene

$$\begin{array}{c} \sim {}^{\mathrm{CH} - \mathrm{CH}_2} & - \mathrm{CH} - \mathrm{CH}_2 \\ 0 & 0 & 0 \end{array} \xrightarrow{- \mathrm{CH} - \mathrm{CH}_2} - \mathrm{CH} - \mathrm{CH}_2 \xrightarrow{- \mathrm{CH} - \mathrm{CH}_2} \xrightarrow{- \mathrm{CH}$$

$$\sim$$
 CH -CH<sub>2</sub> -CH-CH<sub>2</sub> - CH - CH<sub>2</sub> -CH-CH<sub>2</sub> -CH-CH<sub>2</sub>  $\sim$ 

(b) Styrene Rubber Copolymers

Copolymers of styrene with natural rubber or such monomers as butadiene  $CH_2 = CH-CH = CH_2$ .

17. Polyurethanes

Products of reactions between polyhydroxy compounds and polyisocyanates. The iso-cyanate group, -N - C = O is extremely reactive with active hydrogen. Polyurethane foams are made by reacting saturated polyesters, unsaturated dibasic acids, such as maleic acid, and di – and tri-isocyanates such as toluene 2,4 – diisocyanate,

$$\bigcup_{N=C=O}^{CH_3} -- N = C = O$$

18. Polyvinyl Butyral

A copolymer of polyvinyl alcohol and butyraldehyde.

19. Polyvinyl Chloride

A polymer of vinyl chloride

 $CH_2 = CH C_1 - CH_2 - CH C_1 - CH_2$ 

20. Polyvinylidene Chloride

A polymer of 1, 1-dichloroethylene

 $CH_2 = C C I_2 \longrightarrow CH_2 - C CI_2 \longrightarrow$ 

# 21. Silicone Polymers

Polymers in which some of the carbon atoms are replaced by the silicon atoms. Polymers are prepared from mono di, tri, and tetrahalosilanes of the type  $RaSix_b$ , where a + b = 4.

# 22. Teflon

Polytetrafluoroethylene,

$$\begin{array}{cccc} F & F & F & F \\ \hline & F & F & F & F \\ \hline & - & - & - & - & - & - \\ F & F & F & F & F \end{array}$$

## APPENDIX F

## BIBLIOGRAPHY - PYROLYSIS AND DEGRADATION

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# APPENDIX G

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